Characterization of Polymer-Modified Binders for Special Surface Dressings

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The Laboratoire Central des Ponts et Chaussées, a French technical administration department, has put forward a laboratory method for characterizing polymer-modified binders for surface dressings such as emulsions and fluxed asphalt cements. This method has been applied to the most commonly used polymer-modified binders in France. In consultation with contractors, nine binders have been selected. For comparison purposes, an unmodified binder has been added to the list for each category. All of the binders on the list underwent all known practicable laboratory tests. This exhaustive characterization had two objectives: to evaluate the degree of modification of each binder compared with the corresponding reference binder and to simplify the characterization methodology by requiring that only tests that indicate significant aspects of modification be run. To complement the laboratory tests, a traffic simulation test was carried out on a circular traffic simulator to make more lifelike usage comparisons. It has been possible to draw up a classification system and threshold limits, below which binders cannot be considered "modified," for certain specifications.

In the 1970s highways of hydraulic concrete began to present maintenance problems, and it was becoming essential to reestablish their surface roughness. Foreseeing that surface dressings using conventional fluxed binders would not be able to withstand the wear produced by heavy traffic, the administration informed petroleum companies and other interested parties of its interest in polymer-modified binders and that it intended to experiment on certain road sections with any binders they might propose. The administration also organized its own research on the addition of thermoplastic polymers to asphalt cements in order to select the best polymer types.

Since then, surface dressings have played a greatly increased role, and in France around 350 million square meters of pavements are now treated with surface dressings. The use of polymer-modified binders in special surface dressings has become commonplace where traffic is relatively heavy, and it is estimated that about 10 percent of surface dressings applied in France are special dressings with polymer-modified binders.

With such a large market, each civil engineering company has tried to perfect its "very own" modified binder, and this is why it is now necessary to do laboratory characterization to determine the properties of these special surface dressing binders. The Central Public Works Laboratory, the Laboratoire Central des Ponts et Chaussées (LCPC), has therefore suggested a laboratory characterization method for polymer-modified binder emulsions and polymer-modified fluxed asphalt cements.

This method has been applied to the most commonly used polymer-modified binders. In consultation with contractors, nine binders were selected—four emulsions and five fluxed asphalt cements. For comparison purposes, an unmodified binder was added to the list for each category.

All of the binders underwent all known practicable laboratory tests. This exhaustive characterization had two objectives: to evaluate the degree of modification of each binder compared with the corresponding reference binder and to simplify the characterization methodology by requiring that only tests that indicate significant aspects of modification be run. To complement the laboratory tests, a traffic simulation test was carried out on a treadwheel to make more lifelike usage comparisons.

A classification system and threshold limits, below which binders cannot be considered "modified," have been drawn up for certain specifications.

CHARACTERIZATION METHODOLOGY

To evaluate binder characteristics and their short-term evolution as thoroughly as possible, their properties have been determined for

- Fluxed or emulsified binders, known here as "as-they-are" binders, and
- Binders from which the essence of the volatile fraction is removed or that result from the breakup of the emulsion, here called "stabilized" binders.

Laboratory characterization was completed by treadwheel simulation. This intermediate step between laboratory and on-site use was applied only to stabilized binders.

In practice a stabilized binder is obtained by oven testing a film 1 mm thick (for fluxed binders) and a thickness corresponding 1 mm of residual binder (for emulsions) at 50°C in ventilated conditions for a fortnight. In the case of emulsions, breaking is obtained by simple water evaporation at 50°C. Table 1 gives the tests carried out on as-they-are binders and stabilized binders. The tests were run in conformity with the French standards (AFNOR), the LCPC working methods, or the test methods described in the Appendix.

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TABLE 1 TESTS CARRIED OUT ON AS-THEY-ARE AND STABILIZED, FLUXED, MODIFIED BINDERS

Test	Working Method	As-They-Are Binders	Stabilized Binders
Penetration at 25°C	NFT 66 004		X
Ring-and-ball softening point	NFT 66 008	X	X
Fraass brittle point	M.O. RLB 7 project	X	X
Elongation at −10°C	See Appendix	X	X
Elongation at +20°C	See Appendix		X
VIALIT cohesion	See Appendix	X	X
Treadwheel traffic simulation	See Appendix		X

INTERPRETATION OF TEST RESULTS

The following characteristics will be examined:

- Consistency as noted in penetration, ring-and-ball, and Fraass tests;
- Elongation behavior at constant speed;
- Cohesion noted with VIALIT pendulum ram;
- Adhesion and cohesion measured with a VIALIT plate (only for anhydrous as-they-are binders); and
- Traffic simulator behavior at Total's French research center.

Consistency Characteristics

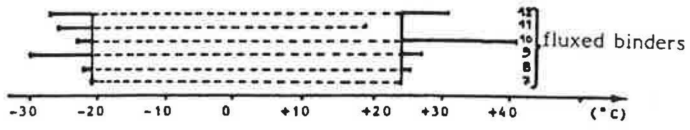
Under this heading can be grouped measurements of ring-and-ball softening point (RBP), Fraass brittle point, and penetration. The object of modifying binders with polymers is to reduce thermal susceptibility at normal usage temperatures because this leads to reduction of the brittle temperature level and increases the softening temperature level and therefore the plasticity range. In the case of fluxed binders, spraying viscosity temperatures remain compatible with equipment used and aggregate wetting. Comparisons therefore are more important between plasticity ranges that are directly related to the binder's modification level than between the RBP and Fraass values taken separately. Each manufacturer can, for a given plasticity range, favor hot or cold behavior characteristics by the choice of asphalt cement or the amount and nature of fluxing oil, or both. Figure 1 shows the absolute plasticity range stages compared with reference binders (1 and 7) for each binder category (emulsions and fluxed bitumen) for both states (as-they-are and stabilized).

Examination of these results leads to some general comments:

- For as-they-are binders (binders 7 to 12), the plasticity range goes from 45°C for the reference binder 7 up to 64°C for binder 10, in other words a maximum increase of around 20°C. It should be noted that the modified binders 9 and 11 are not different from traditional binders in this respect.
- For stabilized fluxed binders, evaporation of the volatile fraction is accompanied not only by consistency increases but also by an increase in the plasticity range (on average, 10°C); the overall classification order remains virtually the same.

Modified binders can be clearly distinguished by their plasticity ranges.

a) as-they-are binders (except emulsions)



b) stabilized binders

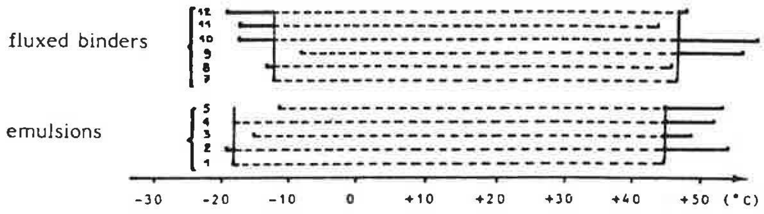


FIGURE 1 Plasticity range: Fraass and ring-and-ball.

Elongation Characteristics

The elongation trial working method is briefly described in the Appendix, and the results are shown in figures.

As-They-Are Binders

For fluxed bitumens, the trial is carried out at −10°C. Figure 2 shows the average curves.

Under these conditions, all of the binders cross the flow threshold. Stress falls more or less quickly—the higher the threshold the faster it falls—and reaches a zero value in the case of reference binder 7. This is characteristic of ductile behavior. For modified binders, stress keeps a value above zero that can increase with lengthening (binder 10). This latter type of curve represents viscoelastic behavior similar to that of an elastomer. It should be remembered that this is the type of behavior sought when binders are modified for surface dressings.

Elongation of Stabilized Binders at 20°C

Curves of the as-they-are binder types at −10°C are shown in Figure 3. A consistency increase due to evaporation of a part of the fluxing oils appears to have compensated for the softening caused by the test temperature. The same general remarks are therefore applicable.

Elongation of Stabilized Binders at −10°C

After evaporation of the volatile fraction (and breaking of the emulsions), the binders have clearly differentiated elongation behavior at −10°C (Figure 4):

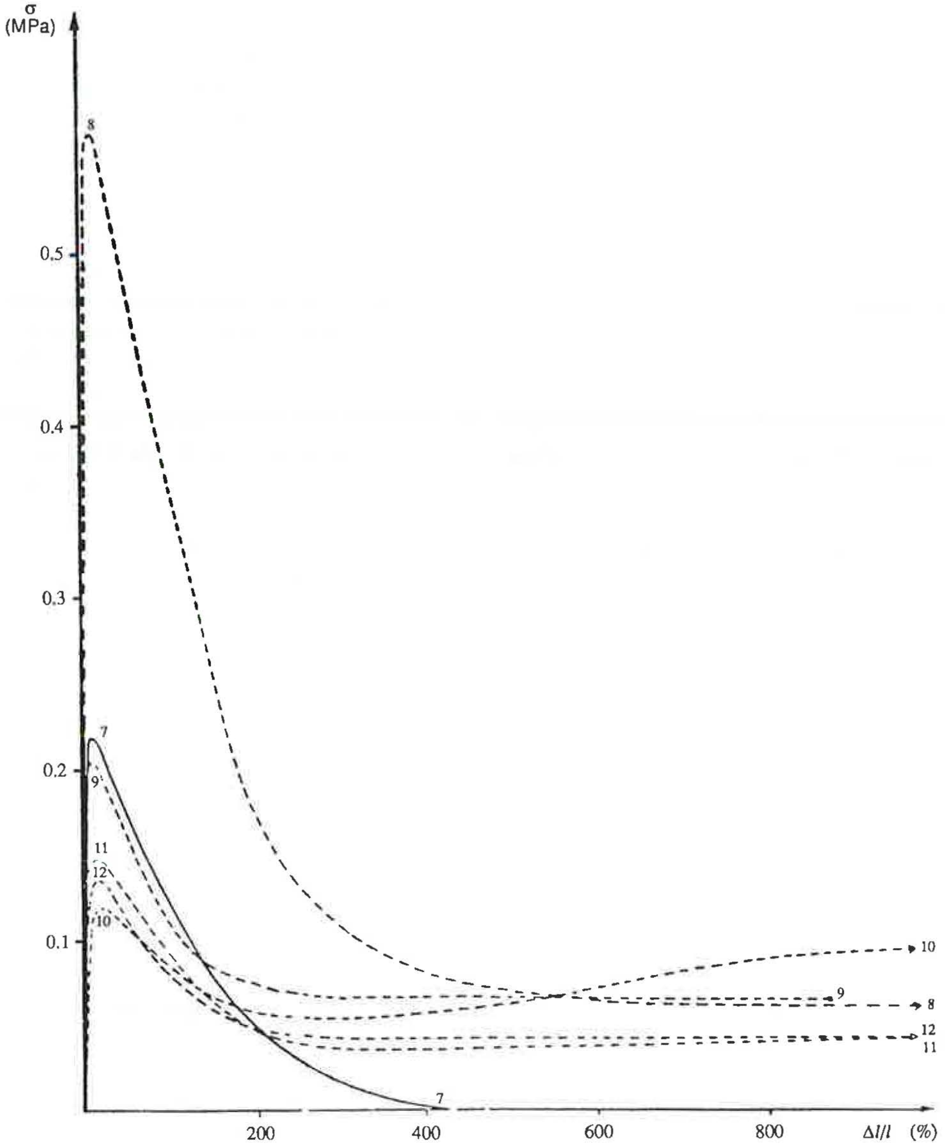
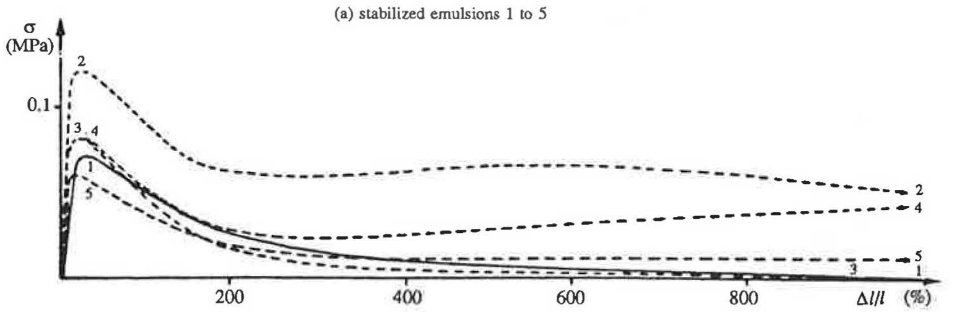


FIGURE 2 Curves of average stress/lengthening at −10°C, 100 mm/min for as-they-are binders (fluxed asphalt cement).


(a) stabilized emulsions 1 to 5

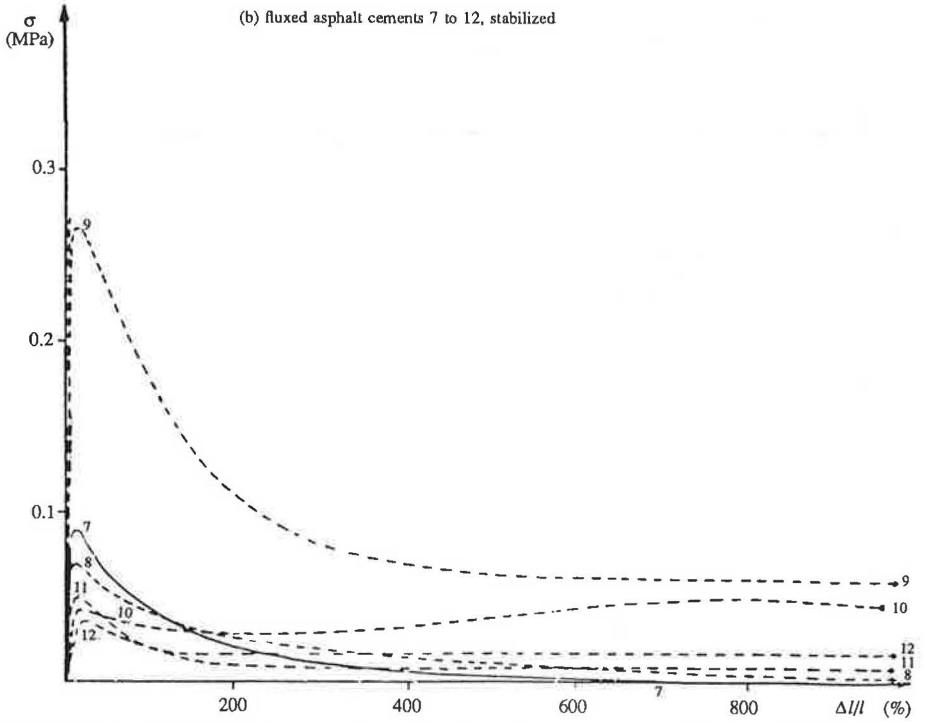

(b) fluxed asphalt cements 7 to 12, stabilized

FIGURE 3 Curves of average stress/lengthening under elongation at +20°C, 500 mm/min.

- Only two modified binders (10 and 12) cross the flow threshold at a speed of 100 mm/min;
- Reference binders 1 and 7, and also modified binder 9, are brittle even at a speed of 10 mm/min; and
- All of the other binders (emulsions 2 to 5 and fluxed asphalt cements 8 and 11) cross the flow threshold at an elongation speed of 10 mm/min.

The information obtained from the elongation trials carried out on modified binders in different conditions is fairly homogeneous. The behavior of stabilized binders, which is markedly different at −10°C, is already different at +20°C and shows up in the behavior of as-they-are binders at −10°C. Stabilized binders that are not brittle at −10°C produce considerable break lengthening (more than 800 percent) at 20°C (or at −10°C for as-they-are binders) corresponding to equally great stress compared with the threshold stress level.

Furthermore, 20°C cannot be considered a high working temperature, and it appears that the most interesting information on stabilized binders is obtained at −10°C, which is a low working temperature. The elongation trial could therefore be considered an indication of the degree of modification associated with possibilities of deformation under cold conditions.

Cohesion Using a VIALIT Pendulum Ram

One of the essential reasons for adding polymers to binders for surface dressings is to increase cohesion. The VIALIT pendulum ram is a simple means of evaluating the energy absorbed by the breaking of a binder film (see Appendix). Trials of each binder are carried out at various temperatures and a cohesion/temperature curve is drawn.

All of the cohesion/temperature curves have the same appearance. As the temperature drops from the high working values of 60°C to 70°C, cohesion increases in proportion to increasing viscosity and reaches a maximum value that allows a maximum cohesion temperature to be defined. It then decreases from the viscous state to the brittle state and reaches

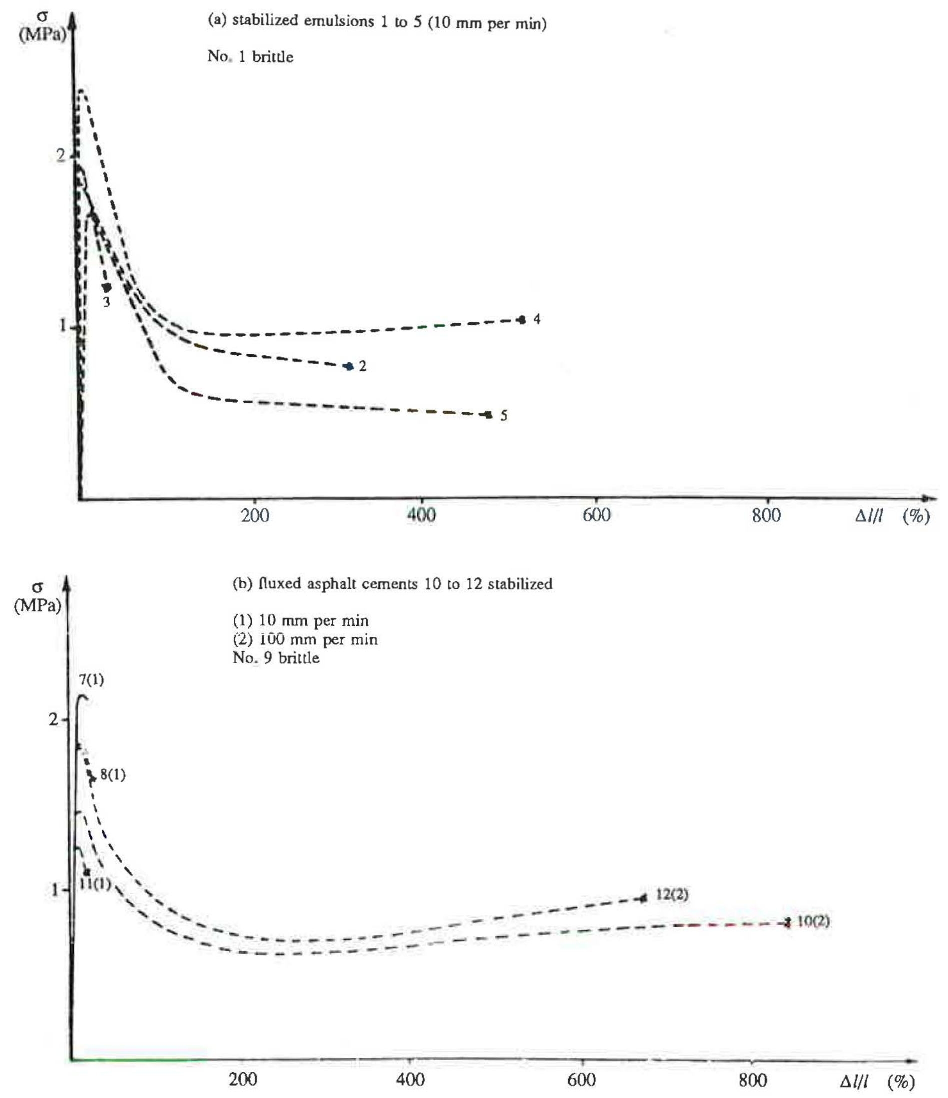


FIGURE 4 Curves of average stress/lengthening under elongation at −10°C.

a low level that is characteristic of a brittle state. Such curves have been established for the anhydrous as-they-are binders and for all of the stabilized binders (Figure 5).

It has been observed that for as-they-are anhydrous binders the introduction of polymers leads to a considerable increase in maximum cohesion that can almost double (binders 10 and 12). The temperature range over which cohesion is increased is also considerably increased, going to as much as 20°C for these binders.

Eliminating the volatile fraction sends the cohesion curve sliding toward the highest temperatures whether or not there is a reduction of maximum cohesion. It should be noted that the maximum cohesion classification order remains unchanged. An examination of stabilized binders resulting from modified binder emulsion breaking leads to observations similar to those made about anhydrous stabilized binders.

It therefore appears that the best modification indicator of both anhydrous and emulsion binders for surface dressings is the value of maximum cohesion measured on the stabilized binder (the value cannot be measured with as-they-are emulsions). The maximum associated cohesion temperature is a reflection more of the product's viscosity than of its degree of modification. It is therefore interesting to know the initial value as well as the variation during evaporation of the volatile fraction of the fluxing oils in the case of anhydrous binders so as to adapt them to the climatic conditions under which they will be used.

Adhesion and Cohesion to the VIALIT Plate

The VIALIT plate test method allows binder/aggregate combination brittleness to be studied under the conditions in which it was created. This test, which was not originally considered as a means of revealing the degree of modification of a binder, has produced sufficiently interesting results for it to be included in this paper. The test consists of making plates of surface dressing (known as VIALIT plates) in a traditional way with dry aggregate and varying the temperature of the ingredients at the moment the aggregate is put into contact with the binder (here, 5°C and 20°C). After compaction, each plate undergoes repeated shocks from the ball starting at +5°C and decreasing by steps of 5°C. The number of chippings remaining on the plate after each series of three shocks and the temperature are noted.

This test was carried out on the six as-they-are anhydrous binders with the three types of reference aggregate generally used for adhesion trials—flint, quartzite, and microdiorite. The results are shown in Figure 6.

Comparison of the left and the right graphs highlights the influence of temperature at the moment chippings are added. Although adhesion created at +5°C may appear to be satisfactory, its fragility is quickly evidenced at a lower stress temperature. This phenomenon is much less pronounced if the chipping temperature is +20°C (see left graphs).

The influence of the type of aggregates used and their cleanliness (even after washing, the microdiorite used was still covered with a clay gangue) is increased under bad damping conditions (5°C) whereas it is much less under better

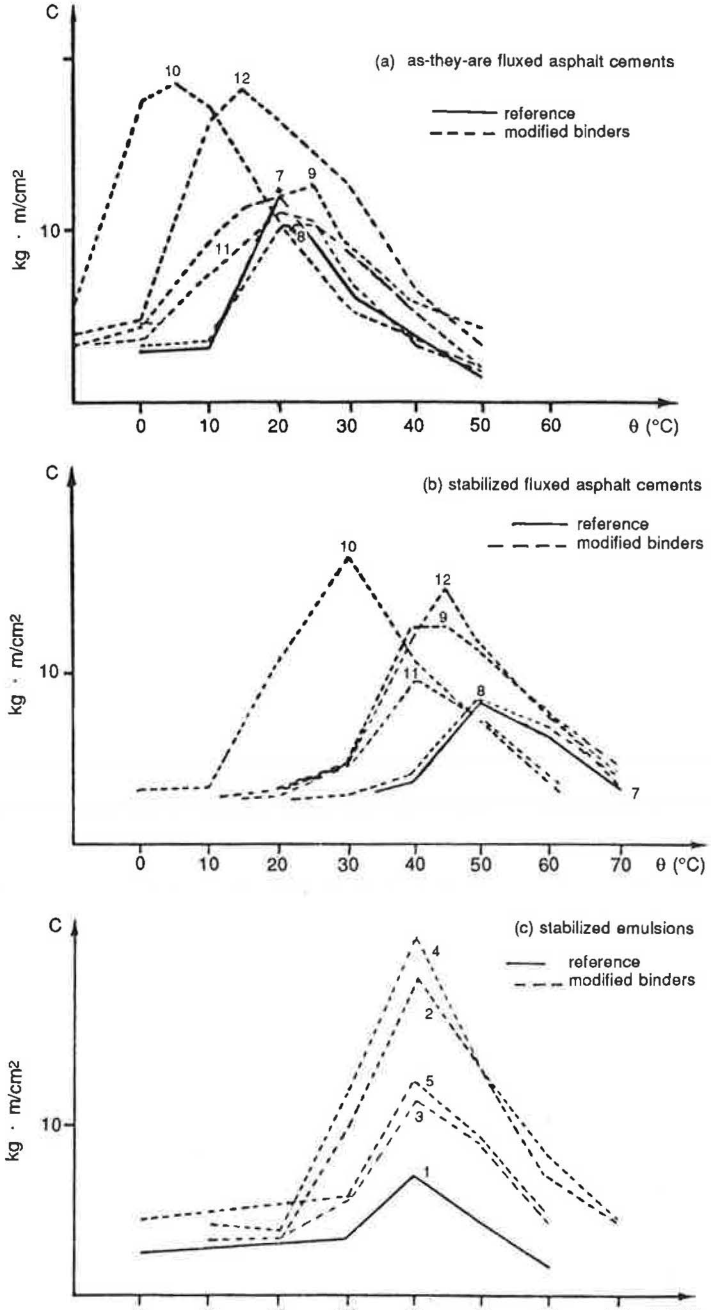
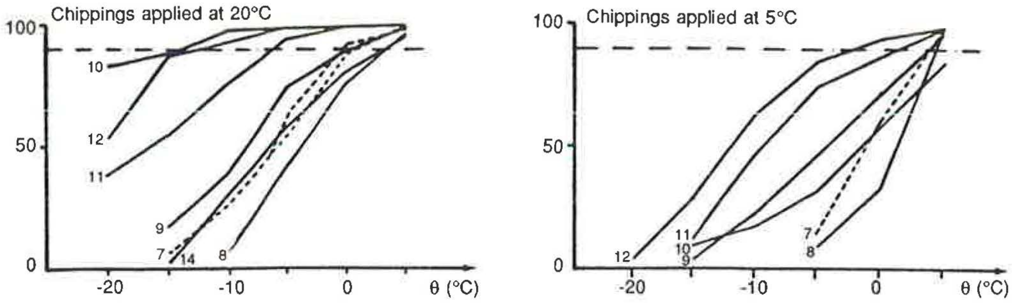
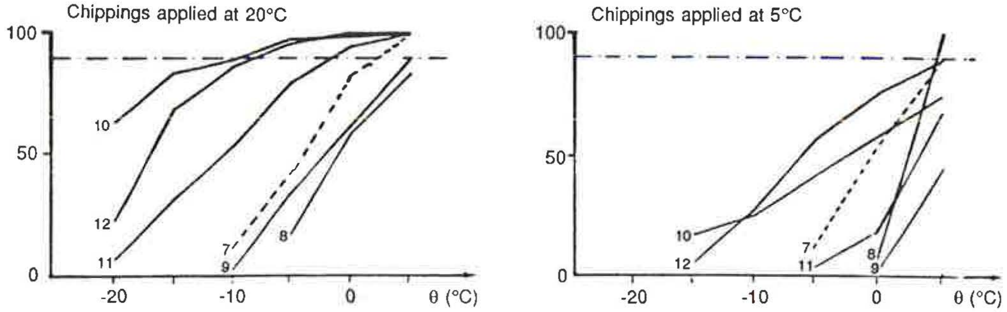


FIGURE 5 Cohesion curves using a VIALIT pendulum ram.


Quartzite 10/14


Microdiorite 10/14

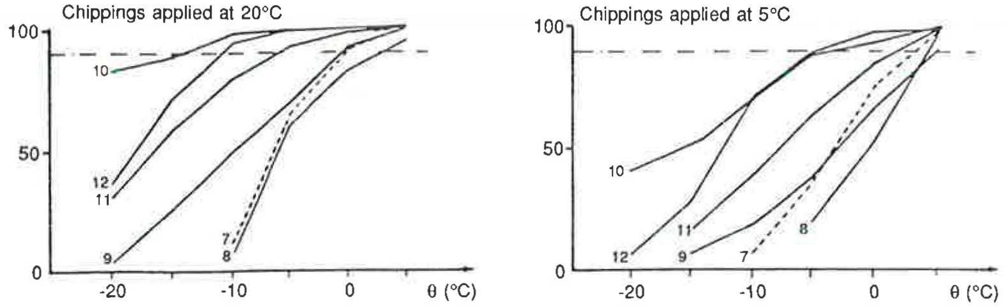

Flint 10/14

FIGURE 6 VIALIT plate test: percentage of different types of aggregate remaining on plate as temperature is decreased.

conditions (20°C). It is therefore imperative to respect minimum temperatures, not only for modified binders but also for the traditional binder 7. For this reason, comparisons are based on curves established at 20°C.

This trial concerns both binder/aggregate adhesion, which tends to take place at the beginning of the curves at around 50°C, and binder cohesion that takes place at low temperatures. The empirical results are therefore generalized and quite similar to practical usage conditions. The indicator chosen is the temperature that corresponds to 90 percent of the aggregate remaining attached to the plate.

Circular Trials

This test is used to study, at various temperatures, how well chippings attached to a surface dressing remain attached after the repeated passage of a loaded, constantly braking wheel. The quality of the binder content to be studied is estimated by examination of the appearance of the test bar, and the quantity by observing the chippings rejection rate. The working method of this test is described in simplified form in the Appendix. The chippings rejection rate per number of passages of the wheel is shown in Figure 7.

Behavior comparisons on the treadwheel concern only stabilized binders that have been prepared under conditions in which damping is correctly carried out with hot aggregates and support. The choice of the two test temperatures was based on experience in previous studies and confirmed by the first results of the present study.

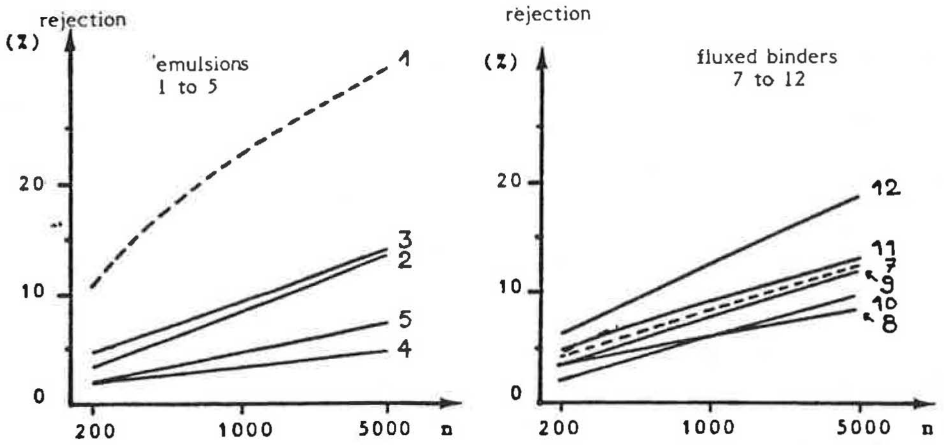
It was known that

- The variation in the rejection rate due to temperature goes through a minimum,
- The minimum rejection temperature is fairly closely linked to the maximum cohesion temperature measured with a VIALIT pendulum ram, and
- The most significant rejection rate differences are obtained at temperatures quite far from the minimum rejection temperature.

Examination of the results indicates that, indeed, the difference in behavior is much greater at 5°C because rejection rates after 5,000 revolutions go from less than 15 to more than 80 percent. This temperature can therefore be considered sufficiently low for test conditions although it is still far from the extreme temperatures of actual winter service.

The treadwheel trial at 5°C appears to be suitable for indicating the improvement that modified binders can produce in the resistance of chippings to being torn off by traffic at low temperatures. At 35°C the average rejection rate and its generalization are reduced about 5 to 30 percent. At this

tests at 35°C



tests at 5°C

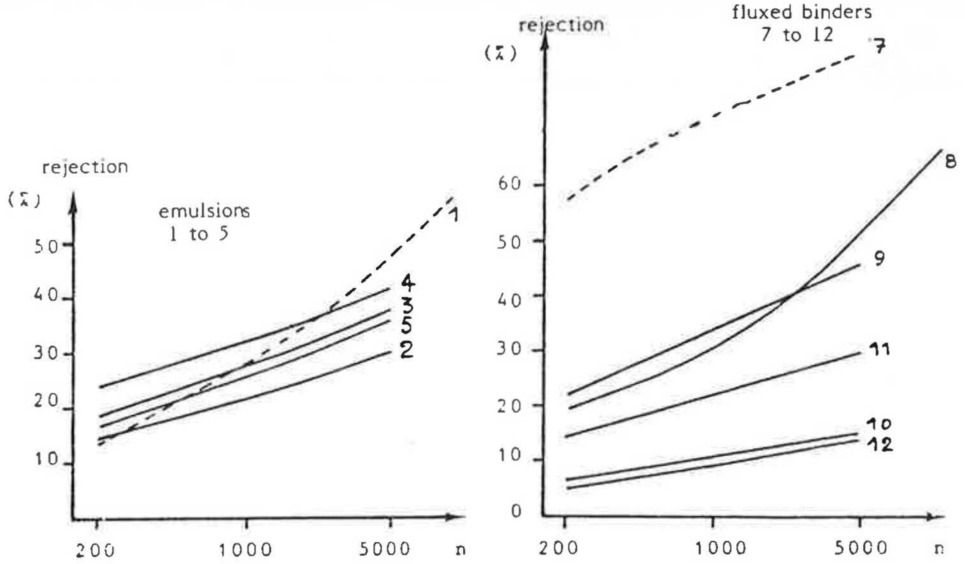


FIGURE 7 Circular traffic simulation: rejection rate per number of revolutions.

temperature, chippings are not rejected by the fracturing of the binder but by a viscous fracture that also leads to chippings being moved, but this is not measured. In addition, the softening of the binder coating triggers the start of tracking and the forcing of chippings into the surface dressing. There is therefore no clear difference between conventional binders and modified binders at this temperature.

COMPARISON OF BINDER CHARACTERISTICS OF STABILIZED BINDERS MEASURED IN THE LABORATORY AND THEIR BEHAVIOR ON TRAFFIC SIMULATION TRACKS

Stabilized binders are the only ones tested on the traffic simulation track. As has already been mentioned, the traffic simulation track trial was more discriminating at 5°C than at 35°C. Problems such as bleeding failure, viscous displacement, and embedding movements of chippings, which appear at higher temperatures, are difficult to measure with the rejection indicator. The ring-and-ball softening point, which is the only indicator to approach high working condition temperatures, is not related to traffic simulator behavior at 35°C whether the rejection rate or the "degree of blackening" be chosen as indicator.

It would therefore appear that the proposed methodology does not allow behavior problems under real, high-temperature working conditions to be satisfactorily appraised. Comparisons of traffic simulator and laboratory results are therefore limited to cold testing (Fraass and elongation at −10°C), as well as specific indicators of modification characteristics associated with the incorporation of polymers that are independent of the temperature plasticity range and cohesion on the VIALIT pendulum. An arbitrary four-level scale was adopted for each binder to compare laboratory tests with treadwheel tests.

The data in Table 2 indicate that

- A close connection exists between the plasticity range and the maximum cohesion measured by the VIALIT pendulum.
- A satisfactory relationship exists between these two criteria and elongation behavior at −10°C. The difference is never greater than one of the classes defined in Table 3.
- A low Fraass temperature is a necessary condition but is not sufficient to obtain important elongation of the fracture at −10°C. If the Fraass lowering is due to a modification of the binder by the polymers, it is accompanied by an increase in the plasticity range and an increase in lengthening at the fracture point in elongation at −10°C. If, on the other hand, it is simply due to a soft binder, the behavior in traction at −10°C remains mediocre. A bad Fraass always leads to fragile behavior under elongation at −10°C.

That traffic simulator behavior is close to the results of laboratory tests shows that none of them can "forecast" traffic simulator behavior. On the other hand, the "average" calculated randomly (without weighting) over the four laboratory tests is fairly close to the traffic simulator "score." Differences that are smaller than or equal to a "class" for the totality of the stabilized binders can be observed.

It therefore appears that the main indicators of the degree of modification of stabilized binders are

- Plasticity range: the softening temperature must be measured by ring and ball, and the fragility temperature by the Fraass method;
- Fracture lengthening under elongation at −10°C for a speed of 10 mm/min;
- VIALIT maximum cohesion, which completes the information given by the plasticity range; and
- The ratio of the stress at 1000 percent with the stress at the flow threshold under elongation at 20°C and 500 mm/min, which is fairly similar to the information obtained under elongation at −10°C.

TABLE 2 STABILIZED FLUXED ASPHALT CEMENTS AND STABILIZED BINDERS OF MODIFIED-EMULSION ORIGIN: SCALE OF VALUES FOR EACH TRIAL

	0	1 +	2 ++	3 +++
Plasticity range (°C)	60	60 à 65	65 à 70	70
Maximum VIALIT cohesion (kg.m/cm²)	5	5 à 10	10 à 15	15
FRAASS (°C)	5	-5 à-10	-10 à-15	-15
Fracture lengthening at -10°C 10 mm/min (%)	10	10 à 100	100 à 1000	1000
Traffic simulator (+ 5°C) rejection after 5,000 cycles (%)	75	75 à 50	50 à 25	25

TABLE 3 STABILIZED FLUXED ASPHALT CEMENTS AND BINDERS OF MODIFIED-EMULSION ORIGIN: COMPARISON OF LABORATORY TESTS AND TREADWHEEL BEHAVIOR AT 5°C

Binder number	1 (1)	2	3	4	5	7 (1)	8	9	10	11	12
Plasticity range	+	+++	+	+-	+	0	0	+	--+	-	---
Maximum cohesion	+	+++	++	--+	++	+	+	++	---	+-	---
FRAASS	+++	+++	++	-++	+-	++	++	+	+-+	+++	---
Elongation at -10°C	0	+-	+	-+	++	+	+	0	---	+	---
Lab. average	+	++-	+	--	++	+	+	+	---	+-	---
Traffic simulator at 5°C	+	++	++	--	+-	0	+	+-	---	--	---

All of these characteristics measured on stabilized binders can be obtained for all binder types, whether they be fluxed or in emulsion. In the case of fluxed binders, certain characteristics measured on the as-they-are binders are also interesting indicators. It has been noticed that stabilized fluxed binder characteristics (VIALIT maximum cohesion and traction behavior) are related to the characteristics of as-they-are fluxed binders.

SUGGESTED METHODOLOGY FOR CHARACTERIZATION OF MODIFIED BINDERS

The methodology suggested here aims at specifying the degree of modification of a binder compared with a traditional binder, and does not claim to prejudge behavior under road traffic conditions of the surface dressing produced from such modified binders. The surface dressing's formulation parameters, such as viscosity adjustments and dosages to the medium, and traffic and climatic conditions have at least as much influence as the degree of modification of the binder.

Moreover, although the tests carried out in this study allow cold binder behavior to be reasonably well characterized, they are less satisfactory for hot binder behavior. In the absence of more satisfactory tests, a minimum ring-and-ball temperature is recommended to avoid the appearance of "soft binders" that might be induced by the proposed methodology. Table 4 gives the test evaluating degree of binder modification and suggests associated thresholds below which binders should not be considered modified.

CONCLUSION

The French administration has invested heavily in modified binder research for special road surface dressings during the past 15 years. This investment was first and foremost in research on procedures for dealing with the mechanisms that modify traditional binder properties when polymers are incorporated. Second, and this is the object of this paper, it was in characterization of industrial binders in cooperation with the manufacturers concerned.

The present study has attempted to find a way to completely characterize modified binders for surface dressings, and has led to

- Improvements in knowledge of the intrinsic characteristics of each binder through laboratory tests;
- The discovery that a close connection exists between characteristics of binders and their behavior on a circular traffic simulator;

TABLE 4 TESTS SELECTED AND THEIR ASSOCIATED THRESHOLDS

Characteristic	Threshold
As-They-Are Anhydrous Binders	
Plasticity range (°C)	≥ 50
Maximum cohesion (kg·m/cm^2)	≥ 12
Elongation at −10°C (100 mm/min)	
Fracture lengthening (%)	> 1000
Stress ratio at 1000% and at flow threshold	> 0.1
Stabilized Binders	
Plasticity range (°C)	≥ 60
Maximum VIALIT cohesion (kg·m/cm^2)	≥ 10
Elongation at 20°C (500 mm/min)	
Fracture lengthening (%)	> 1000
Stress ratio at 1000% and at flow threshold	> 0.1
Elongation at −10°C (10 mm/min)	
Fracture lengthening (%)	> 100
Ring-and-ball temperature (°C)	≥ 50

- A suggested characterization methodology using only the most useful tests: plasticity range, VIALIT pendulum ram cohesion, and direct elongation at different temperatures; and
- Suggested threshold limits for these characteristics below which the degree of modification of the properties compared with traditional binders can be considered too small.

This paper represents an important step forward in knowledge of modified binders but does not claim to resolve all of the problems; in the future more work should be done, particularly on

- The behavior of modified binders at high operating temperatures (a suitable laboratory test method should also be sought) and
- The relationship between laboratory- and treadwheel-determined characteristics and the behavior of binders under traffic.

APPENDIX: Brief Description of the Trials

Elongation

During an elongation test at constant speed (500, 100, 10, or 1 mm/min), the stress/lengthening variation is measured. The test bars are of the H2 type (Figure A-1) as defined by the French Standard NFT 5134 of December 1981. The initial length used in the calculations is the distance between the jaws, which equals 50 mm.

Test temperatures are −10°C and +20°C for stabilized binders. For fluxed binders only −10°C is usable because their consistency prevents tests at +20°C. For each temperature, the results are given for the maximum speed possible that does not lead to fracturing before the flow threshold is reached. For example, a result expressed at −10°C and 10 mm/min means that the binder is brittle at this temperature for the next higher traction speed of 100 mm/min.

Each result is presented as pairs of average values (stress and lengthening) measured at the flow threshold and at the fracture point and an average curve produced from at least five repetitions.

VIALIT Cohesion

The principle of the test (Figure A-2) is to measure the energy absorbed by the fracturing of a binder film under a given impact. The binder to be tested is used to stick a grooved-surface steel cube to a grooved-surface steel stand. The cube has two 1-mm shims that allow a binder plate to be made up that is 1 mm thick with a 1 cm^2 section.

The cube undergoes the shock of the pendulum ram, and the binder holding the cube breaks across its thickness. A graduated dial equipped with a nonreturn needle measures the maximum swing of the ram by steps.

This test is carried out twice: the first time, the cube is stuck to its stand by the binder; the second time, the cube is not stuck to the stand. A conversion table allows the energy for each angle to be calculated.

Cohesion is equal to the difference between the energy necessary to knock off the cube stuck on with the binder and that necessary to knock off the unstuck cube.

Tests were carried out at temperatures between −30°C and +60°C for each binder. The cohesiveness curves were then drawn relative to temperature.

VIALIT Adhesion

This test is based on the principle described in the preproject Overall Adhesion Test of a VIALIT Plate of March 1973. It consists of making surface dressing plates (VIALIT plates) by using traditional methods with dry aggregates and varying the temperature of the components when they are put into contact with the binder and aggregates (here, 5°C and 20°C). After compaction, each plate undergoes a series of shocks from the ball at decreasing temperatures (starting at 5°C and decreasing by steps of 5°C). The number of chippings re-

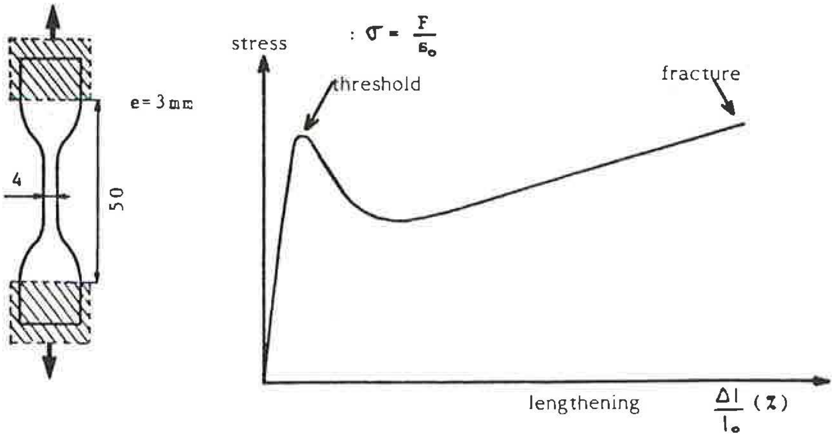


FIGURE A-1 H2 test bar and typical traction curve.

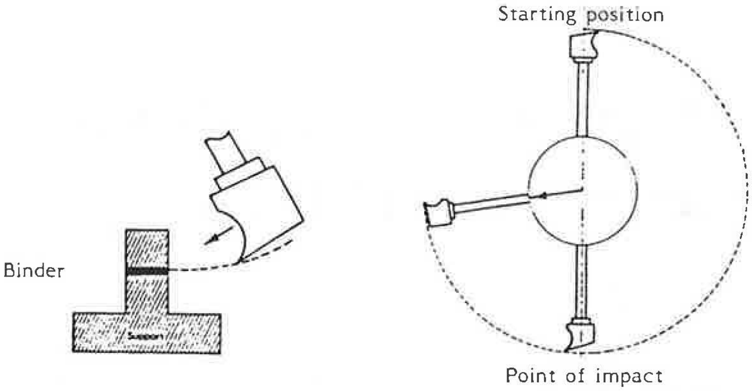


FIGURE A-2 VIALIT pendulum ram.

maining on the plate is noted after each series of three impacts, as is the temperature. The results are presented as a variation graph that shows the cumulative number of chippings remaining and the temperature.

Circular Traffic Simulator (by Total, France)

This test aims at an overall estimate of the qualities of a modified or unmodified binder for surface dressings by studying chippings' resistance to being torn off the test surface dressing at different temperatures under conditions similar to those of real life.

A loaded and constantly braking wheel turns on a test bar of surface dressing made using the binder to be studied. At each test temperature, the binder's holding power is estimated qualitatively by examining the test bar's appearance and quantitatively by measuring the chippings rejection rate.

The trial test bar consists of a 0/10 bituminous concrete support (40/50 bitumen, compaction level above 95, 6 cm thick) covered with a 6/10 single layer of surface dressing produced with the binder to be tested at a rate of 1.5 kg/m^2. The binder to be tested is heated to test temperature (in this case 5°C and 35°C). A probe placed on the binder to be tested gives the exact temperature of the surface dressing, and a second probe gives the inside temperature.

Test conditions for each temperature were as follows:

Parameter	*Value*
Wheel speed	12 km/hr
Load	300 kg
Tire pressure	2.5 × 105
Braking torque	3 m · daN

During the test, which lasts 5,000 cycles, rotation is interrupted at least four times (e.g., at 300, 600, 1000, and 2000 turns), and the torn-off chippings are vacuumed up and weighed. The results are given in graph form showing the rejection rate and the number (n) of revolutions of the treadwheel ($0 < n < 5000$).

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