# Optimization of Porous Mixes Through the Use of Special Binders

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The studies carried out in the laboratory to value the effect of the use of special binders in the manufacturing of porous mixes are covered in this article. The results obtained from the use of polymeric bitumens and conventional binders are compared. These studies were conducted in the Road Laboratory of the University of Cantabria and in the E.S.M. Research Center. It also reflects the performance of some sections constructed with polymeric bituments as compared to the response of porous pavements fabricated with conventional binders.

In recent years, the use of porous mixes as a wearing course has demonstrated enormous advantages and many road technicians, especially in Spain, are selecting them. This use has made evident the properties to be emphasized in these mixes in order to achieve good medium- and long-term performance: on the one hand, resistance to disintegration and, on the other, porosity.

The basic mechanical characteristic to be taken into account in the design of these mixes is the resistance to disintegration. An observation of sections in service reveals that scabbing, potholes, and aggregate losses appear very frequently in this type of pavement. These deficiencies stem from a drop in the cohesion of the mix, making it unable to adequately resist the abrasive effect of traffic.

In addition, these mixes must have a high degree of porosity if their beneficial effect on the circulation of vehicles is to be appreciable and maintained on a medium- and long-term basis. The advantages that these mixes offer for improvements in traffic circulation in wet conditions are directly related to their permeability. The greater the permeability, the greater the pavement's drainage capacity and the more difficult it will be to encounter splashes or vehicle skidding.

The acoustics of these mixes also depend on their porosity. The greater the porosity and the thicker the draining course, the greater the pavement's capacity to reduce traffic noise and improve the quality of life of those living near the road.

The initial porosity achieved also functions to maintain these properties over a long term. With a low initial percentage of porous, (16 to 18 percent, the filling of these mixes usually takes place in a short period, and they lose a large part of their initial properties. One can deduce from the experience of the pavements in service that it is convenient to design these mixes with a high percentage of porous (more than 21 to 22 percent), in order to maintain a high degree of their permeable characteristics during their active life.

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A problem arises because the two properties considered are in opposition. An increase in porosity always represents a loss of cohesion and less resistance to disintegration in the manufactured mix. In fact, it is sometimes difficult to reach a satisfactory solution with the use of conventional materials and binders, and it becomes necessary to resort to special binders in order to improve their properties and, at the same time, achieve elevated porosity and adequate cohesion.

Moreover, utilization of these special binders has other effects which must be considered when using this type of mix. They increase the film thickness of the binder and reduce the risk of binder runoff when the mix is transported. They also improve the mix's adhesion and its resistance in the action of atmospheric agents.

The studies carried out in the laboratory to evaluate the effect of the use of special binders on the manufacturing of porous mixes are covered in this article. The results obtained, from the use of polymeric bitumens and the use of conventional binders, are compared. These studies were carried out in the Road Laboratory of the University of Cantabria and in the E.S.M. Research Center. The performance of certain sections constructed with polymeric bitumens compared with the response of porous pavements constructed with conventional binders are also discussed.

## LABORATORY STUDY

The laboratory study centered on the effect produced by the incorporation of polymeric bitumen on the following properties of the mix:

- Resistance to plastic deformations,
- Resistance to indirect traction,
- Resistance to disintegration,
- Adhesiveness, and
- Runoff.

The grading of the mix studied is that of a continuous open type, ophite aggregate, with the following characteristics: maximum size, 10 mm; percentages passing through the sieves of 5, 2.5, and 0.080 mm, 30, 10, and 4 percent, respectively.

Two bitumens of a similar penetration are used with this grading, one having been modified by the incorporation of a mix of polymers.

These two binders were chosen prior to laboratory analysis of different types of polymers and their effect on bituminous binder. For this study, an 80/100 bitumen was chosen, modified by the incorporation of an EVA type polymer, whose

characteristics are given in Table 1. (Toughness and tenacity are measured by pulling a hemispherical screw-head out of binder specimen at 25°C.) The same table also includes the characteristics of the B-60/70 bitumen used. The differences between the binders are notable, especially with respect to their toughness and thermal susceptibility.

### Resistance to Plastic Deformations

The study of the resistance to plastic deformations was carried out with the use of the wheel tracking test at a temperature of 60°C. The percentage of binders over aggregates tested ranged from 4.0 to 4.5 percent for both mixes.

In Figure 1, it can be observed that with the use of polymeric bitumen, there is greater resistance to plastic deformations than with the mix fabricated with ordinary bitumen, which is itself resistant and displays good performance in practice, and represents greater security in the face of this type of deficiency.

The use of polymeric bitumens can diminish the effect of postcompacting by traffic, which is sometimes observed in porous mixes.

### Resistance to Indirect Traction

The effect of the binder on improving resistance to traction of this mix was studied through the rupture of Marshall test samples at a diametrical compression.

The tests were carried out at two temperatures: 5 and 45°C, and for a charge application velocity of 50.8 mm/min. The Marshall test samples were compacted with an energy of 50 blows per face, in accordance with the compacting energy employed in the sections and the densities reached.

The test results, as can be seen in Table 2 and Figure 2, show a better performance of the mix made with polymeric bitumen compared with that made with ordinary bitumen. This difference is more significant at 45°C than at 5°C, which leads to the belief that the use of a lower rupture velocity would have made manifest the difference with respect to flexibility and toughness presented by these two binders in use.

Nevertheless, the results obtained show an increase in the traction resistance of 20 to 30 percent for polymeric bitumen with respect to ordinary bitumen at 45°C.

### Resistance to Disintegration

This is perhaps the most valuable property in these mixes and it is here that the effect of the bitumens modified with polymers becomes more evident.

Disintegration resistance is tested in the laboratory through the Cantabro test of wear loss, consisting of introducing Marshall samples into the Los Angeles machine (without balls) to obtain their weight loss after 300 drum revolutions. This test has been used as a basis for Spanish standards for establishing design criteria for these mixes. In accordance with this test, Spanish design criteria are the following:

- The voids in mixes should be more than 18 percent and, preferably, not less than 20 percent, and
- The test loss will be no more than 35 percent and, generally, no more than 30 percent, if the test is carried out at 18°C.

These values refer to Marshall test samples compacted by 50 blows per face.

The final results clearly show the advantages of using polymeric bitumens over traditional ones. For the same binder

TABLE 1 CHARACTERISTICS OF THE BINDERS TESTED

| | B - 60/70 | Polymeric bitumen |
|---|---|---|
| Penetration at 25 °C (0,1 mm) | 65 | 70 |
| Softening Point (°C) | 50 | 68 |
| Penetration Index | - 0,5 | + 1,9 |
| Fraass Point (°C) | - 8 | - 13 |
| Plasticity Index (°C) | 58 | 81 |
| Toughness (Kg.cm) | 4 | 157 |
| Tenacity (Kg.cm) | 95 | 229 |

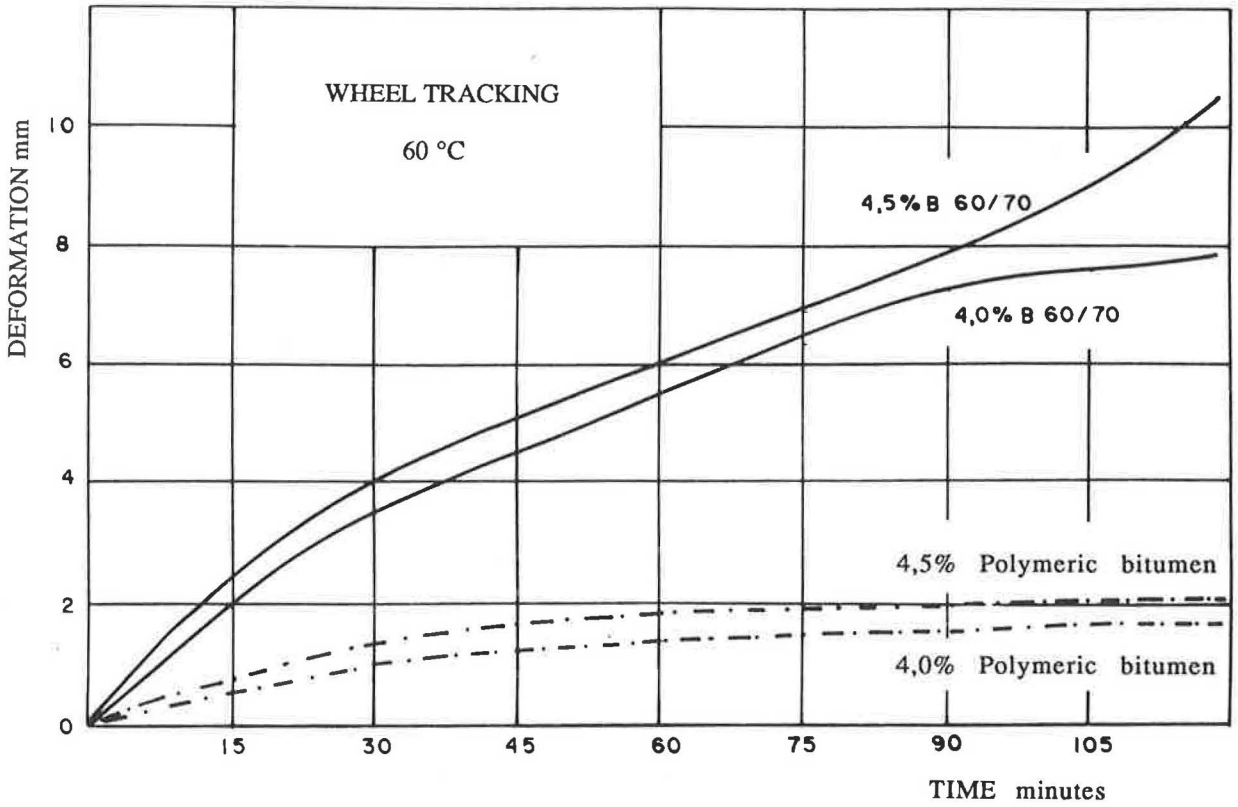


**FIGURE 1 Resistance to plastic deformation.**

TABLE 2 EFFECT OF TEST TEMPERATURES AND PERCENTAGE OF BINDER ON ULTIMATE TENSILE STRENGTH.

| | Ultimate tensile strength (Kp/cm2) | | | | | |
|---|---|---|---|---|---|---|
| | 3,5% binder | | 4,5 % binder | | 5,5% binder | |
| Test temp. °C / Binder type | 5 | 45 | 5 | 45 | 5 | 45 |
| Polymeric bitumen | 71,5 | 3,8 | 72,5 | 3,5 | 70,1 | 3,1 |
| B - 60/70 | 65,4 | 2,9 | 69,6 | 2,9 | 71,0 | 2,7 |

content and with similar void percentages, the use of polymeric bitumens reduces the losses by 15 to 20 units, as can be seen in Table 3 and Figure 3. Thus, the non-utilization of polymeric bitumen would result in the rejection of the selected mix according to Spanish standards, except for the use of 5.5 percent of binder with the consequent loss of voids in the mix and the possible problem of binder runoff.

### Adhesiveness

Another important property to be considered in these mixes is their resistance to the stripping effect caused by water. Their high porosity favors this water action, which can cause rapid disintegration of the mix in cases using aggregates and binders with a deficient adhesiveness factor.

In this study, the resistance to this stripping action was evaluated in the Cantabro wear test be determining the loss in the test sample that was submerged in water at 49°C for four days.

The results, given in Table 3 and Figure 4, show that the mix manufactured with elastomeric bitumen maintains a high resistance to disintegration after the period of water immersion, even higher than that displayed when dry by the mix manufactured with B-60/70 bitumen. On the other hand, the mix fabricated with ordinary bitumen loses a large part of its

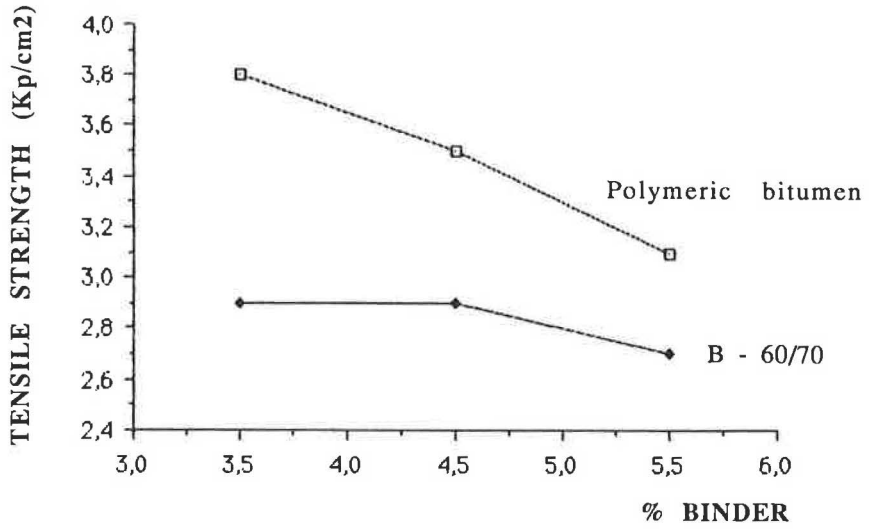


**FIGURE 2 Influence of binder type on tensile strength (indirect traction test at 45°C).**

TABLE 3 VOIDS AND LOSSES IN THE TWO MIXES TESTED IN THE CANTABRO WEAR TEST

| | B - 60/70 | | | Polymeric bitumen | | |
|---|---|---|---|---|---|---|
| % binder s. a. | 3,5 | 4,5 | 5,5 | 3,5 | 4,5 | 5,5 |
| Voids (%) | 24,1 | 22,2 | 20,2 | 24,1 | 22,1 | 19,9 |
| Dry losses | 46 | 40 | 33 | 30 | 20 | 15 |
| After immersion (%) | 86 | 65 | 50 | 52 | 32 | 24 |

cohesion, resulting in very high losses in the tests, even for the 5.5 percent binder.

These results emphasize the greater adhesiveness of the polymeric bitumen compared with ordinary bitumen, which can also be seen in the increase in losses in the tests after the immersion period. Thus, although the increase in test losses for the polymeric bitumen after the immersion period ranges from 9 to 22 points, this gain varies from 18 to 40 points for ordinary bitumen.

### Runoff

This problem sometimes occurs in these mixes, especially when they are manufactured with a low fines content and a high percentage of binder. In such cases, it is possible that a runoff of the binder to the bottom of the truck layer may occur during transport. This represents a weakening of the bitumen and a loss of the mix's cohesiveness, which may rapidly become evident by its quick disintegration by traffic.

The tests carried out in the laboratory to ascertain the influence of the binder type on runoff showed, as can be observed in Table 4, that the use of a polymeric bitumen can notably reduce runoff, especially when vibration exists, as normally occurs in the transport of this mix.

The test consisted of putting 1,000 g of mixture into a capsule and introducing it for 1 hour into an oven at the test temperature of 140 or 160°C. After the time had elapsed, the capsule's contents are emptied and the parts that adhered to the walls are weighed. When the test is conducted with vibration, the test continues, after taking the capsule out of the oven and before pouring its contents, with a series of shakings on the table for 15 minutes for compacting test samples of cement mortar.

The results demonstrate that, at 140°C and with vibration, a runoff of ordinary bitumen is clearly produced while for the polymeric bitumen it remains at very low values, barely staining the bottom of the capsule.

## POROSITY VERSUS RESISTANCE TO DISINTEGRATION

The design of porous mixes must compromise between porosity and resistance to disintegration. The porosity is necessary

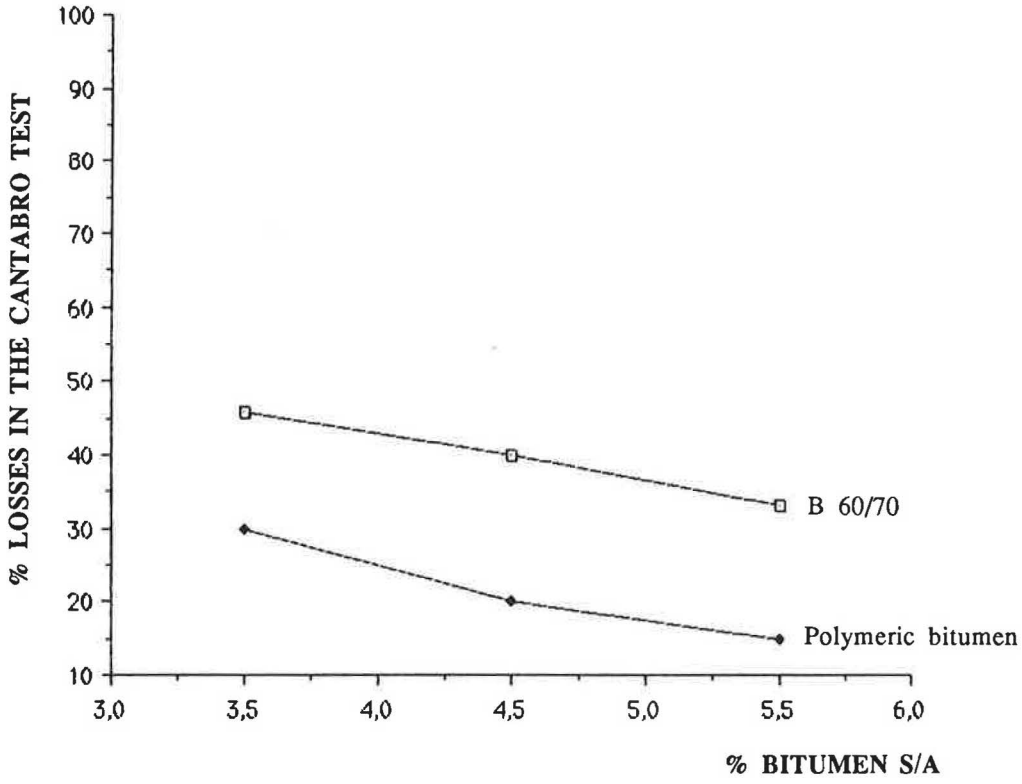


**FIGURE 3 Effect of the type of binder on losses in the Cantabro test.**

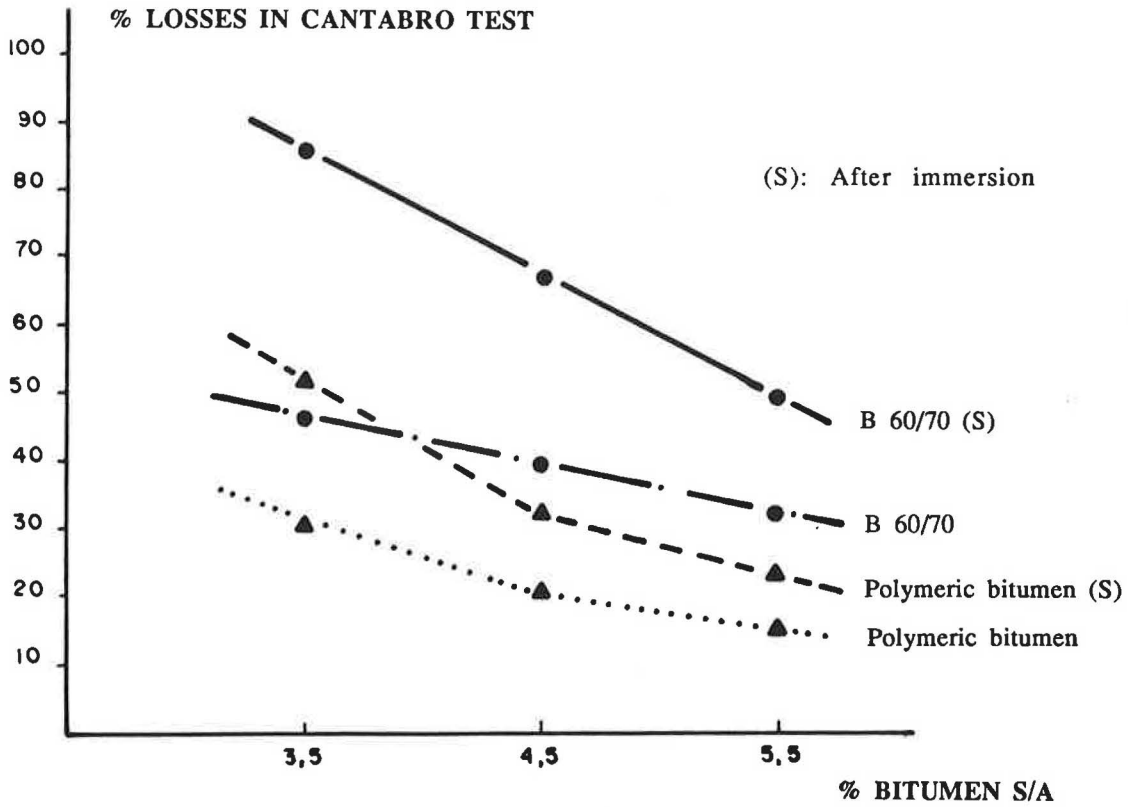


**FIGURE 4 Effect of binder on adhesiveness.**

TABLE 4 INFLUENCE OF BINDER TYPE ON PERCENTAGE OF DRAINED WEIGHT

| | Without vibration | | With vibration | |
|---|---|---|---|---|
| | 5% of binder | | 5 % of binder | |
| Test temp. °C / Binder type | 140 | 160 | 140 | 160 |
| Polymeric bitumen | 1,4 | 1,9 | 1,8 | 4,0 |
| B - 60/70 | 1,6 | 2,0 | 5,1 | 5,3 |

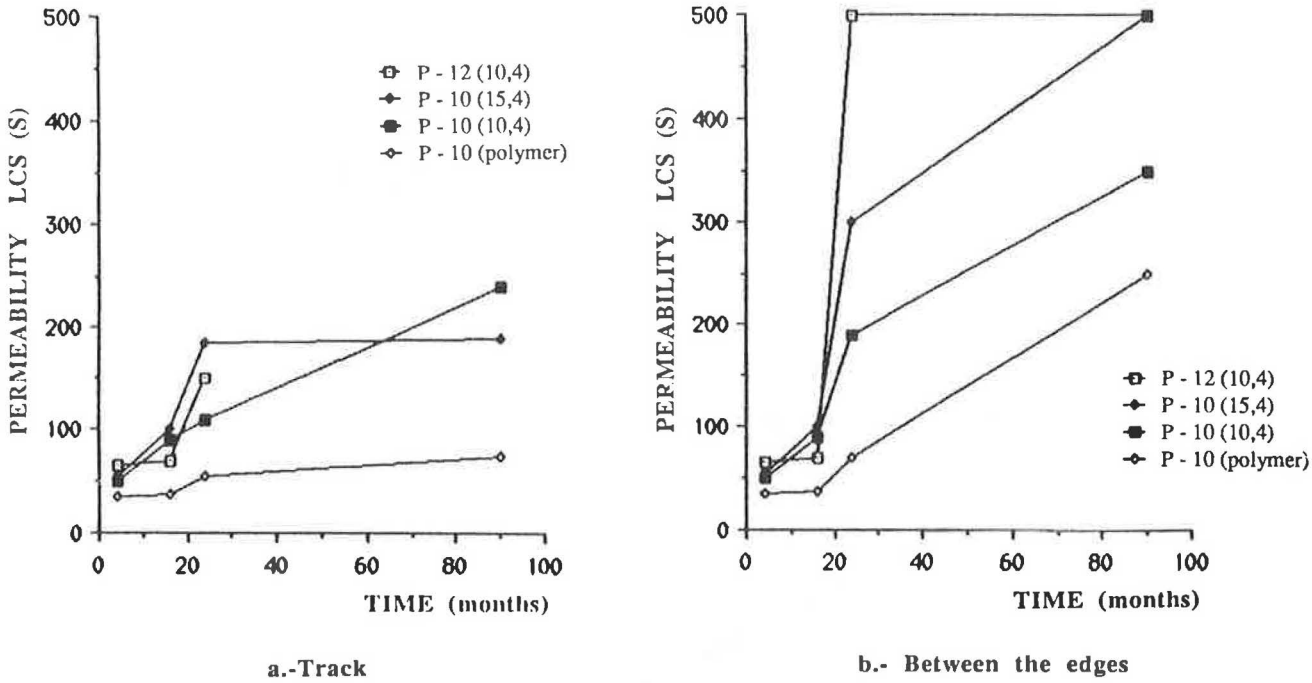


FIGURE 5 Evolution of permeability with time.

to appreciate to a high degree the qualities that these mixes possess and maintain these qualities over a certain period. The resistance to disintegration is necessary for the mixes to resist the tangential stress and suction of traffic without disintegrating.

One frequent problem is that sometimes it is not possible to manufacture mixes that are highly permeable and, at the same time, resistant to the abrasive stress of traffic with conventional materials.

Available experience points to the fact that it is easy for the filling-up to occur in these mixes if one does not start from a high percentage of voids (more than 20 to 21 percent). It is necessary to surpass this porosity if these mixes are to be genuinely permeable and maintain their porosity over time.

The graph of Figure 5 shows the evolution of the permeability measurement on a test section of porous mix (N-634 road) over 7½ years. The following defects can be observed:

1. There is differential filling up caused in the lane, (Table 5. In the wheel track zones, the vehicles' suction force has a cleansing effect, helping to maintain the permeability of the mix, and
2. When using low porosities, filling up may easily result.

Only the P-10 mix, which contains polymeric bitumen, maintains an appreciable permeability after 7½ years.

The void-loss ratios of the two mixes tested in the laboratory, graphed in Figure 6, show that only by using a modified

TABLE 5 EVOLUTION OF PERMEABILITY WITH TIME

| | Solares-Beranga sections | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Evacuation time (s). LCS permeameter | | | | | | | |
| Mix type and void | P-12 (10,4) | | P-10 (15,4) | | P-10 (10,4) | | P-10 (polymer) | |
| Track zone | Track | Between edges | Track | Between edges | Track | Between edges | Track | Between edges |
| 4 mths. (1) | 65 | | 55 | | 50 | | 35 | |
| 16 mths. (1) | 70 | | 100 | | 90 | | 38 | |
| 2 years | 150 | 500 | 185 | 300 | 110 | 190 | 55 | 70 |
| 7,5 yrs. | | 500 | 190 | 500 | 240 | 350 | 74 | 250 |

(1): Average value.

P - a (b,c): a.- maximum aggregate size
b.- % pass 2.5 mm UNE
c.- % pass 0.080 mm UNE

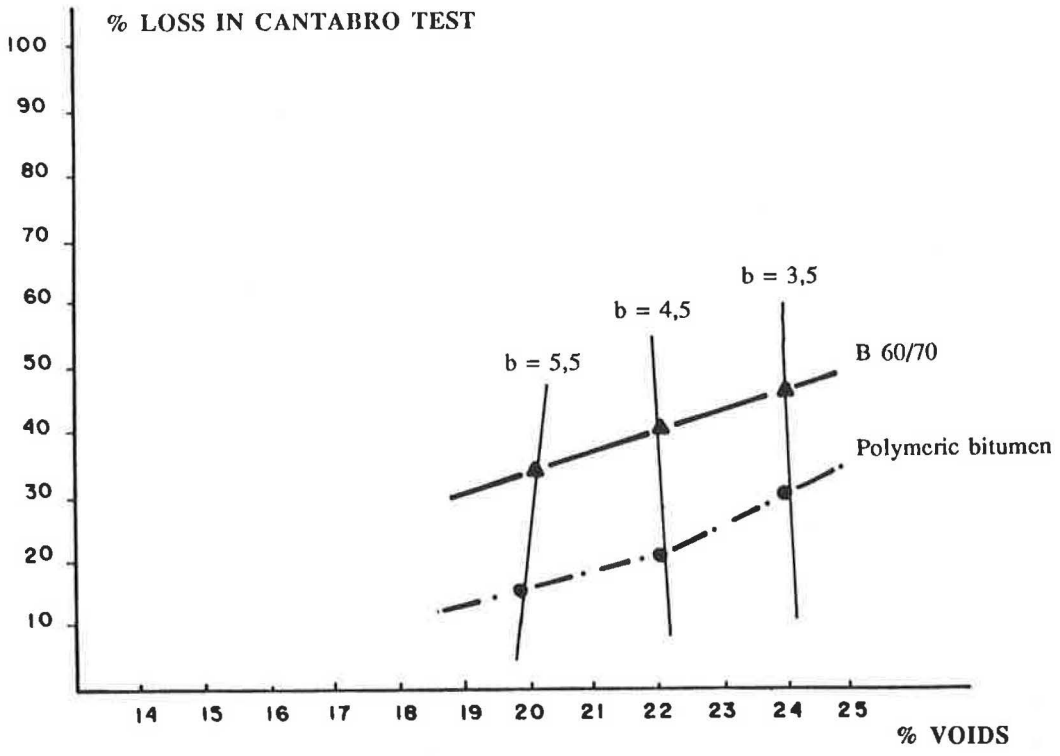


**FIGURE 6 Ratio of voids to losses.**

binder can highly porous mixes (> 20 percent for the percentage of voids) be achieved that are simultaneously resistant to disintegration (< 30 percent for losses).

## BEHAVIOR OF SECTION IN USE

The results obtained for the different roadways in which polymeric bitumens are used are almost the same. As can be seen in Table 6, mixes of similar gradings and binder content have been employed in these. For example, the results corresponding to the A-8 freeway from Bilbao to Bohobia are included, where the aforementioned characteristics are being wholly and continuously measured.

### Permeability

After more than two-and-a-half years of service, a slight filling up of the mix employed has occurred. The water evacuation time, measured with the LCS permeameter, has gone from 16 to 35 seconds. [See Table 7. Measurement of permeability: time (in sec) of evacuation of water in the LCS (Laboratorio de Caminos de Santander) permeameter.]

This slight reduction (a predictable one, in any case), has no appreciable effects on the efficiency of water drainage and the avoidance of its projection and splashing. It should be kept in mind that, after this type of service, the mix still remains a coefficient of permeability of $20 \times 10^{-2}$ cm/sec, higher than that of a permeable sand.

### Macrotexture

By using a sand circle procedure, the tests carried out a year after its installation give values ranging from 1.8 to 2.2 mm, indicating an excellent superficial macrotexture.

### Coefficient of Longitudinal and Transversal Friction

The measurement of the longitudinal friction coefficient with the Road Research Laboratory friction pendulum showed an initial value of 0.49, increasing after opening to traffic, as a consequence of the disappearance of the binder film covering the surface of the aggregates. After one month, it was already 0.55 and after six months, 0.61.

TABLE 6 ROAD WORKS UNDERTAKEN

| Date | Place | Grading UNE sieves % passing 12.5 | 10 | 5 | 2.5 | 0.08 | bit. (%) | Voids (%) | Cantabro (%) Dry | Wet |
|---|---|---|---|---|---|---|---|---|---|---|
| 4-80 | Solares | 100 | 85 | 36 | 18 | 5.5 | 4.5 | 20 | 12 | - |
| 12-80 | Orense | 100 | 87 | 25 | 16 | 3.5 | 4.5 | 20 | 12 | - |
| 2-82 | Solares | 100 | 82 | 32 | 14 | 3.5 | 4.8 | 20 | 14 | - |
| 4-82 | Pamplona | 100 | 87 | 36 | 15 | 4 | 4.6 | 21 | 13 | - |
| 3-86 | A-8 (*) | 100 | 85 | 35 | 13 | 3.5 | 4.5 | 21 | 12 | - |
| 85 | Orense | 100 | 87 | 25 | 16 | 4 | 4.5 | 20 | 15 | - |
| 3-86 | A-8 | 100 | 94 | 31 | 11 | 4 | 4.5 | 22.5 | 13 | 29 |
| 7-86 | A-6 | 98 | 82 | 24 | 12 | 4.1 | 4.3 | 22 | 8 | - |
| 87 | Irurzun | 100 | 87 | 28 | 13 | 4 | 4.5 | 21 | 18 | 35 |
| 9-87 | Oviedo | 100 | 86 | 28 | 16 | 4 | 4.4 | 20 | 16 | 37 |
| 10-87 | Las Rozas | 100 | 84 | 22 | 14 | 4 | 4.5 | 22.5 | 12 | 24 |
| 1-88 | La Avanzada | 100 | 85 | 27 | 13 | 4 | 4.3 | 23 | 14 | - |
| 3-88 | Vigo | 100 | 91 | 21 | 17 | 4 | 4.0 | 22 | 17 | 32 |
| 3-88 | Lugo | 100 | 86 | 19 | 12 | 4 | 4.5 | 21.6 | 10 | - |
| 6-88 | La Coruña | 96 | 59 | 20 | 14 | 4.7 | 4.5 | 21.4 | 12 | 22 |
| 9-88 | Pontevedra | 100 | 87 | 29 | 21 | 4.7 | 4.5 | 21.4 | 13 | 25 |
| 9-88 | Palencia | 84 | 77 | 21 | 17 | 4 | 4.5 | 22.3 | 11 | 22 |
| 12-88 | Orense | 100 | 82 | 28 | 16 | 4 | 4.5 | 22.5 | 11 | 22 |
| 12-88 | Barcelona | 100 | 87 | 28 | 15 | 3 | 4.5 | 21.7 | 16 | 28 |

(*): A-8, Bilbao-Behobia Freeway

TABLE 7 BILBAO-BEHOBIA FREEWAY. EVOLUTION OF THE INITIAL CHARACTERISTICS OF THE MIX

| | Service time | | | | |
|---|---|---|---|---|---|
| | Initial | 1 month | 6 months | 1 year | 2,5 yrs. |
| LCS permeability (s) | 16 | 20 | 24 | 29 | 35 |
| Coef Longitudinal Friction RRL pendulum | 0,49 | 0,55 | 0,61 | 0,61 | |
| Coef. Transversal Friction SCRIM | | 50-70 | | 70-75 | 60-75 |

TABLE 8 EFFECT OF THE TYPE OF PAVEMENT ON VEHICLE NOISE

| TYPE OF PAVEMENT | dB(A) sonority | |
|---|---|---|
| | Dry | Wet |
| Porous mix 0/12 mm | 74,2 | 74,8 |
| Dense mix 0/12 mm | 76,8 | 78,5 |
| Slurry seal 0/8 mm | 77,8 | 80,2 |

The measurement of the transversal friction coefficient with SCRIM shows that, after an initial value ranging from 50 to 70, it increased and then established itself in a variation interval of 60 to 75.

### Rolling Noise

The measurements carried out by the Industrial Testing and Research Laboratory of Bilbao in different sections and pavements of the highway indicate the following: for porous mix, cold microasphalt concrete (slurry seal 0/8 mm), and dense conventional hot mix, the draining agglomerate is shown to be quieter and the cold microasphalt concrete to be noisier, with level differences between them, at 5m, of 3 to 5 dB(A). (See Table 8)

The data recorded in rainy conditions show an increase of 2 dB(A) when driving in wet conditions on the slurry seal and the conventional dense hot mix, and only a slight increase for sections paved with porous mixes.

### Noise Inside the Vehicle

Measurements carried out on this freeway by the SEAT Acoustics and Vibrations Laboratory on a SEAT Malaga vehicle, demonstrate a lower noise level on draining pavements. In the spectral analysis in octave thirds, for the driver's position as well as the passenger's position, a reduction of up to 5 dB(A) is observed in low and middle frequencies with respect to the slurry seal and of 2 to 3 dB(A) with respect to the conventional dense hot mix.

## CONCLUSIONS

The test results make clear the advantages of using bitumen modified with polymers in the properties and characteristics of the porous mixes. These advantages can be summarized as follows:

- The use of polymeric bitumen makes it easier to obtain a greater thickness of the binder film, which improves the cohesion, resistance to aging, and durability of the mix.
- For a minimal value of the content in voids, the wear losses in the Cantabro test are spectacularly lower when using polymeric bitumen compared with pure binders of the same penetration.
- They lead to the obtention of mixes with a higher content of voids without their abrasion resistance being affected. The obtention of mixes with void content equal to or more than 20 percent and abrasion losses of less than 30 percent requires the use of modified binders.

- This ease in obtaining more open mixes results in greater endurance of the initial permeability.
- The tests after immersion show excellent performance of the binder modified with polymers. Its use produces half the losses caused by abrasion of a normal bitumen, which supports the excellent passive adhesiveness of the mentioned binder's properties, and is of great importance in this type of mix.
- Lower criticalness in the manufacture of draining agglomerates resulting from the null risk of under-dosification because of running off of the binder in the manufacturing or extending process.
- The track test results confirm the lower thermal susceptibility of the polymeric bitumen and its superior performance in the face of plastic deformation.