Porous Asphalt Mixtures in Spain

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Currently Spain has 3 million m² of porous asphalt roads. Porous asphalt is being used for all types of traffic conditions and for any type roads and highways. The most common practice today is to use 4 cm layers with 0/12 gradings, with a very low amount of sand (about 15 percent) and 4.5 percent of pure or modified bitumens which results in a voids content in the mix of more than 20 percent.) In the first application of porous asphalt, a conservative approach was taken, primarily using mixes with a moderate content of voids (15 percent to 18 percent). The good durability of mixes with voids contents of more than 20 percent in the experimental road sections and the closing up observed in the mixes with a low voids content has meant that since 1986 the more open mixes have been preferred. Porous asphalts with voids content of less than 20 percent have varied widely in their behavior. With heavy traffic, they have closed up after 2 years' use. With medium traffic, however, they have maintained their drainage capacity after 9 years. None of the pavements using this material have shown any serious deterioration. Despite reduced drainage capacities, all the pavements, including those that have closed up, show a dry appearance during light rains or immediately after a heavy rainfall. Until now, the skid resistance has been very good. Porous asphalts with voids contents higher than 20 percent held up very well even under heavy traffic, although in this case the experience has covered only three years. As in the case of the other mixtures, these have not shown any serious deteriorations, and after several years, they maintain excellent skid resistance.

The first application of porous asphalt in Spain was in 1980 on four experimental road sections on one of the northern highways located in a region of frequent rainfall. Initially, the objective was to use these mixtures in rainy areas in order to improve traffic safety and comfort on wet surfaces.

The favorable results obtained from these mixtures has promoted the construction of new experimental pavements and small projects to be carried out in the next few years. But in 1986, this material started to be used extensively, after initial doubts about its durability were eliminated. Now, the purpose for using this material has changed. It is not only used to improve driving conditions in the rain, but also to provide a durable surface, with a smooth, safe, and quiet ride in any type of weather.

Currently Spain has 3 million m² of porous asphalt roads. Porous asphalt is being used for all types of traffic conditions and for any type of roads and highways. The most notable projects are the 44 km (about 500,000 m²) on Highway N-VI, between Las Rozas and Villalba, with some 20,000 vehicles per day per carriageway, 2,000 of which are trucks (13 ton axle load); the 70 km (about 800,000 m²) on the toll road between Bilbao and Behobia, with about 9,000 vehicles per carriageway, of which 1,200 are trucks, and the 33 km (400,000 m²) in ACESA toll roads, with traffic varying between 800 and 1,800 trucks per day.

The most common practice today is to use 4 cm layers with 0/10 or 0/12.5 gradings, with very little sand, and 4.5 percent of pure or modified bitumens which results in a voids content of more than 20 percent.

MATERIAL REQUIREMENTS

Gradings

The selected aggregate grading primarily influences the water drainage capacity, resistance to particle losses, resistance to plastic deformation, and macrotexture of the mix.

For porous asphalt, two grading bands have been defined, P 12 and PA 12 (Table 1).

The P grading band has a discontinuity in the 2.5 mm size. These gradings usually need three commercial aggregates (0/2.5, 2.5/5, and 5/10 to 12 mm). Using them, mixes with 15 to 22 percent of voids can be obtained. The PA grading band has a discontinuity in the 5 mm size and needs only two commercial aggregates. It was initially designed to reduce the number of commercial aggregates and obtain more open mixes. With these gradings, mixes with up to 25 percent of voids can be obtained.

Both P 12 and PA 12 have a large proportion of coarse aggregate (between 90 and 78 percent of particles exceeding 2.5 mm), in order to accommodate the other components in their interstitial voids, leaving the designed voids in the mix. The amount of fine aggregate must be low enough to prevent the voids from closing up and separating the coarse particles. A certain amount of filler (at least 3 percent) is thought necessary to give cohesion to the mix and avoid particle losses. Keeping this in mind, the tests used to define the grading bands were mainly directed towards the drainability and resistance to particle losses.

Today there is a tendency towards PA gradings, with 10 to 15 percent of particles passing through the 2.5 mm sieve and amounts of filler between 3 and 4.5 percent. With these mixtures, voids contents of more than 20 percent are being obtained.

The maximum particle size has been set at 10 or 12.5 mm for both gradings, although the 10 mm top size is generally

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TABLE 1 GRADINGS

	% PASSING						
GRADING	20mm	12,5mm	10mm	5mm	2.5mm	0.63mm	0,08mm
P - 12	100	75-100	60-90	32-50	10-18	6-12	3-6
PA - 12	100	70-100	50-80	15-30	10-22	6-13	3-6

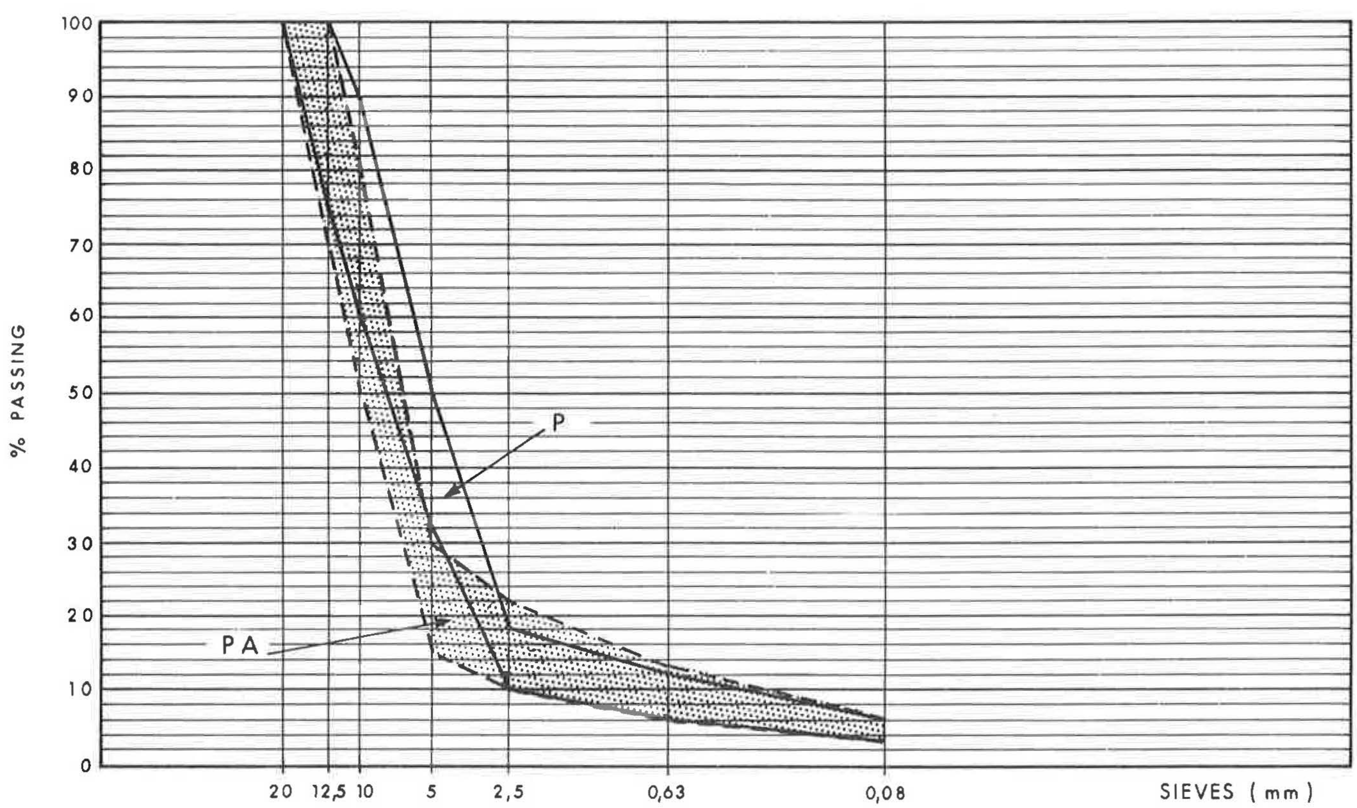

FIGURE 1 Gradings.

used. With this size, sand patch depths of between 1 to 2.5 mm can be obtained. These sizes are also related to the thickness of the layer being used (4 cm).

Aggregates

Considering that the material is for a thin, open, top layer, coarse aggregates which show great resistance to fragmentation, good and stable microtexture, and adequate interlock are called for (Table 2).

Fragmentation of aggregates can lead to particle losses, raveling, and the closing up of the surface texture by the separate fines. An abrasion loss value (Los Angeles machine) of 20 percent is considered as a maximum. For the same reason, a flakiness index below 25 is required.

Frictional characteristics of the surface make a nonpolishing aggregate necessary for maintaining a good, durable micro-

TABLE 2 AGGREGATE CHARACTERISTICS

LOS ANGELES	< 20
FLAKINESS INDEX	< 25
POLISHED STONE VALUE	> 0.45 - 0.40
PARTICLES (%) WITH 2 OR MORE FRACTURED FACES	100 - 75
SAND EQUIVALENT	> 50

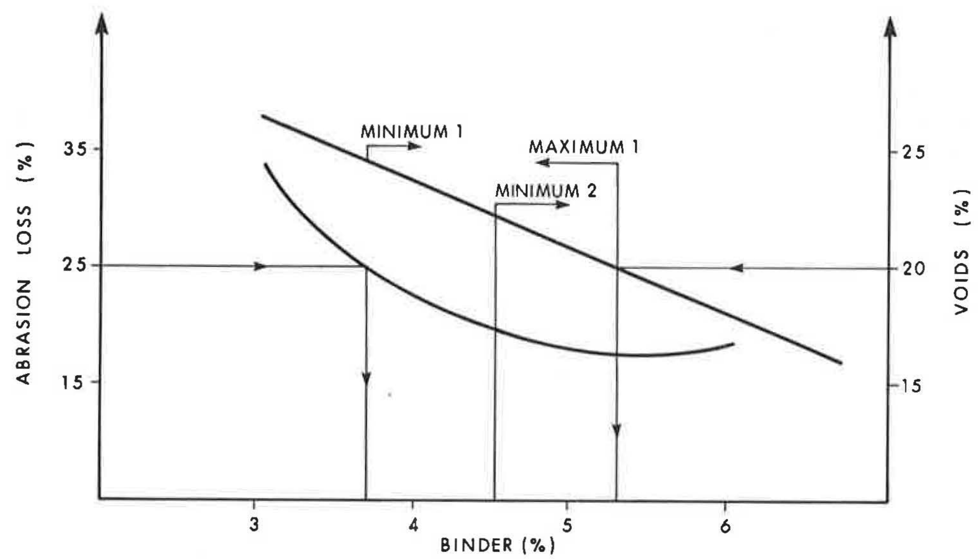

FIGURE 2 Binder design.

texture. The specification sets polished stone values (British polishing wheel) above 0.45 for traffic volumes of more than 800 trucks per day per lane, and 0.40 for other traffic volumes.

Porous asphalt mixtures are subjected to the direct effect of the traffic loads. A good level of internal friction in the course aggregate is necessary in order to avoid plastic deformations and the closing up of the voids. For traffic volumes of more than 800 trucks per day per lane, 100 percent of particles with two or more fractured faces are required. This is reduced to 90 percent for volumes of 200 to 800 trucks and to 75 percent for trucks below 50 per day per lane.

In projects carried out until now, coarse aggregates, which come from hard rocks with a high resistance to polishing (ophites, porphyry, and granite), have been exclusively used. In some cases, limestone has been used for shoulders. Another project used a coarse-grained limestone in a carriageway on the island of Mallorca where no other aggregates were easily available. Until now, the performance has been satisfactory.

Limestone is frequently used as fine aggregate because of its adhesion to the binder. Mineral filler is always added (commercial limestone dust or cement). To avoid the presence of detrimental fine dust, a sand equivalent value above 50 is required.

Hydrocarbonated Binder

In porous mixes, because of the open texture, a thick film of binder coating is sought in an attempt to offset early aging. From this viewpoint, hydrocarbonated binders with high viscosity would be preferred. On the other hand, hard bitumens would take less time to reach a critical hardness of the binder. For this reason, an equilibrium is necessary.

In selecting the binder, other factors to consider are weather and traffic volume. Soft bitumens tend to bleed under high temperatures and can lead to plastic deformations in the mix, particularly under heavy traffic volumes. In cold climates, hard bitumens can produce brittle mixes.

Taking all this into account, in Spain the grades of binder specified are B 60/70 and B 80/100. The former is recommended in areas of mild and hot climates for heavy traffic. But the binders more commonly used are polymer (EVA and SBS) modified bitumens. Today 80 percent of the porous mixes existing in Spain have a modified binder. The main purpose for using it are to improve the resistance against particle losses with very open mixtures through a higher cohesion, and get longer durability through thicker films of binder because of the higher viscosity. A reduction in the thermal susceptibility of the mix (porous mixes are very susceptible to temperature changes) is also sought in an attempt to get higher consistencies with high temperatures and more flexibility with low temperatures (Table 3).

Nevertheless, it has not been possible to confirm the laboratory results on the road. In the first experimental pavements, where mixes with a low amount of voids were laid, pure and modified binders were compared. Until now, there have been no differences in performance. With very open mixes in which the differences probably would be more marked, modified binders have always been used. It is therefore not possible to compare.

The current tendency is to continue using modified binders with the more open mixtures and with heavy traffic, but to experiment with the same mixtures with pure bitumens for medium and light traffic. (There is already an experimental pavement along these lines near Madrid.)

MIX DESIGN

The design of porous asphalt is based on:

- A minimum binder content to assure resistance against particle losses resulting from traffic and a thick film of binder on the aggregates, and
- A maximum binder content to avoid binder runoff and have a good drainability in the mix.

The resistance to particle losses is analyzed through the Cantabro test (NLT-352/86), an abrasion and impact test conducted in the Los Angeles rattler, without balls and at controlled temperature, on Marshall samples compacted with 50 blows on each side. The results are given as the weight loss, in percentage, after 300 drum revolutions (Table 4). The maximum abrasion loss value admitted is 25. With this test, a minimum amount of binder is determined. In any case, the binder content must be at or above 4.5 percent to ensure adequate coating thickness.

The calculation of voids is made on the same Marshall samples, considering the volume geometrically determined. For a specific grading, the minimum amount of voids set (20 percent), define a maximum content of binder. Also there is a maximum binder content to prevent drainage of the asphalt from the aggregates, although this is not yet under specification.

With this procedure, it must be considered that the use of the Marshall hammer for compacting the specimens can cause

TABLE 3 HYDROCARBONATED BINDERS

<table>
<tr><td rowspan="2">TRUCK ADT
IN DESIGN LANE</td><td colspan="3">SUMMER TEMPERATURE</td></tr>
<tr><td>HOT</td><td>MEDIUM</td><td>TEMPERATE</td></tr>
<tr><td>> 2.000</td><td colspan="3">60/70</td></tr>
<tr><td>2.000-800</td><td colspan="3" rowspan="2">60/70 OR 80/100</td></tr>
<tr><td>200-800</td></tr>
<tr><td>50-200</td><td rowspan="2"></td><td></td><td rowspan="2">80/100</td></tr>
<tr><td>< 50</td><td></td></tr>
<tr><td colspan="4">BINDER</td></tr>
</table>

TABLE 4 BINDER CONTENT DESIGN

BINDER CONTENT	PROPERTY OF THE MIX	SPECIFICATION
MINIMUM	RESISTANCE TO PARTICLE LOSSES (CANTABRO TEST)	25
	DURABILITY (% bitumen)	> 4.5
MAXIMUM	BINDER RUNOFF	-
	DRAINABILITY (% VOIDS)	20

some runoff of the binder, mainly with high binder contents. Nevertheless, this leaves the mixture on the safe side in relation to the results of the Cantabro test. Because of the good correlation between voids calculated with this method and drainability in the road and the results of the Cantabro test with laboratory specimens and road samples, this method has been chosen.

In the design of porous mixes, the Cantabro test after immersion and some laboratory permeability tests have been used, but they are not under a standard yet either. Sometimes indirect traction and wheel tracking tests have also been used.

This method usually gives binder contents of about 4.5 percent for normal specific gravity aggregates. With these in practice, no major problems of particle losses or binder runoff have been encountered.

PAVEMENT DESIGN

The design of the newly constructed pavements with layers of porous asphalt mixes has been given in the design standard *Instruction 6.1 and 2.1 C* of the General Direction of Roads of MOPU (*1*).

In this standard, a layer of 4 cm thick is established for porous asphalt. The possibility of using thicker layers has not been considered because the water absorption capacity with 4 cm layers is already thought to be sufficient. Thinner layers would lead to bad performance with heavy rains and could reduce the durability of the layer.

For pavements with granular or asphalt roadbases, the porous asphalt can substitute, in the same thicknesses, for open or semi-open conventional asphalt mixes. This approach has been taken because of the experience and calculations on which the design standard is based. It accounts for pavements with layers of open or semi-open asphalt mixtures, with a mechanical performance similar to those of the porous asphalt.

In pavements with cement-treated road bases, in which one of the main objectives of the bituminous layer is to prevent reflective cracking, a 2 cm increase in total thickness is required for the bituminous layers when porous asphalt is used. This increase is intended to prevent the appearance of reflective cracking in the impermeable layer below the porous asphalt which can make repairs of the structure especially complex and costly.

FIELD OF APPLICATION

Although porous asphalt is used as the top layer of new pavements, the main application thus far has been in the repair of aged or slippery surfaces without structural problems. In this field, this alternative can be more advantageous, from the viewpoint of durability, than others such as those of thin layers of conventional dense-graded mixes, micro-asphalt mixtures, slurry seals, or surface treatments. In specific areas of short length (slippery curves) requiring a very high degree of resistance to skidding, conventional solutions are still preferable. They have also been used in short stretches (300 m) in areas of difficult drainage (change in the direction of the cross fall, low points).

Porous asphalt's use should be carefully studied for the following cases:

- Areas where it snows frequently, because of maintenance problems during the winter months,
- Urban or industrial areas where there is extensive wear from abrasion or where the impacts or spillage of oil or fuels occurs,
- Areas in which a strong risk of reflective cracking exits, either by retraction or fatigue, and
- Bridge pavements, especially in cold areas.

In any case, it is necessary to lay porous asphalt on impermeable and regular surfaces, and to assure adequate lateral drainage.

MANUFACTURE AND LAYING

If porous asphalt is placed over pavements, for surface rehabilitation of an aged or slippery surface, the deteriorated areas should be repaired first and the surface leveled if there are any large irregularities. When porous asphalt is used on pavements with reflective cracking in the surface, it is necessary to seal them first (but this is not a good solution for this type of problem).

In any case, it is necessary to make sure the layer is impermeable and has a satisfactory load capacity. Before the material is placed over new or old layers, an emulsion is extended over it (quick setting cationic emulsion), with a residual bitumen rate of 500 to 600 gr/m^2. In pavements with a highly polished or very open surface, it may be necessary to lay down slurry seals.

The manufacture of the mixture is made in conventional discontinuous plants. The production of the plant should correspond to the spreading equipment in such a way that stops are minimized. When establishing mixing temperatures, binder viscosity must be taken into account, but the drainage of the binder or cooling of the mix during transit from the mixing plant to the job site must also be considered. With B 60/70 or modified binders and the fines given in the specifications, mixing temperatures have oscillated between 140°C and 150°C without ever exceeding 160°C.

In transport, it is necessary to cover the trucks adequately with canvas. In cold weather and over long transport distances, it is necessary to watch out for agglomerated portions of the mixture in the front part of a truck's body.

According to established procedures, this material should not be spread when the temperature is less than 8°C. In any case, the temperature of the mix should never go below 120°C during compacting.

Compacting is carried out with metallic rollers having a total weight of 10 tons or more and without vibration. The usual procedure is to set up two similar compacters. The first compacts with 4 to 5 passes and the second with 2 or 3 in order to smooth out the tracks left by the first one and improve the surface finish.

Until now, shoulders constructed on pavements topped with porous asphalt layers have been built by extending the porous asphalt over the entire shoulder or 50 cm into the shoulder. The top layer of the shoulder in the second case or the intermediate layer in the first case must be of an impermeable material.

The differential aspects of control of this material with respect to conventional mixtures are

- In control of the manufacture, the Marshall test is substituted for the Cantabro Test of abrasion loss on samples in which the voids content has been previously determined, and
- The degree of compaction can be controlled indirectly by means of a permeability test in situ.

This test is conducted by means of the LCS drainometer (*2*). The equipment, developed by the University of Santander in 1981, is a variable charge static outflow meter used to measure the time necessary to drain 1,735 l of water through a pavement surface of 7 cm^2.

The voids content percentage, previously related in the laboratory with the degree of compaction, is then related to the time of water drainage by means of the expression (*3*):

$$H = 58.6/T^{0.305}$$

where

H = % voids content
T = time of water drainage (sec)

MAINTENANCE

The main problems have come in the form of particle losses in localized or large areas. This process usually occurs very quickly once the flow of traffic begins. This problem usually originates from laying the mixture cold, from too low a level of compaction, or from segregation of the binder. The solution has always been to mill and substitute the withdrawn material for another porous asphalt. In one case, the repair was made by laying one porous asphalt over another; so far, no problems have arisen. Rehabilitation has never been undertaken because the material closes up.

Experience with winter maintenance in Spain is not very extensive. Skidding problems have been detected because of ice formation after snowfalls and this has led to avoiding the use of these mixes in extremely cold areas. In warm areas where snow falls only a few days per year, the solution is to use more salt (more than double the normal amount) and increase the frequency of spreading.

PERFORMANCE OF EXISTING SURFACES

In the first application of porous asphalt, a conservative approach was taken primarily using mixes with a moderate content of voids (15 to 18 percent). The good durability of mixes with voids contents of more than 20 percent in the experimental road sections and the closing up observed in the mixes with a low voids content has meant that since 1986, the more open mixes have been preferred. Therefore, in the analysis of the performance of existing pavements with a top layer, it is useful to differentiate the cases in which mixes have been used whose voids content is less than or greater than 20 percent.

Porous mixes with voids content < 20 percent

Experience with these mixes goes back to 1980. They are generally type P gradings with pure bitumens in an application rate of between 4 and 5 percent. The voids content is usually found in the range of 16 to 20 percent. The evolution of the mixes has been studied through measurements of drainability, surface texture, skid resistance, and visual condition.

The initial drainage times (LCS drainometer) on the highway varies between 30 and 75 sec. The texture, measured in sand patch depth, varies between 1 and 1.5 mm. The Side Force Coefficient (SFC) measured with SCRIM type equipment at 50 km/hr and with 1 mm of water gives values of between 0.50 and 0.70. Values of the Skid Resistance Tester Coeficiente (SRC) between 0.45 and 0.70 are usually found.

Over time, a large decrease in the drainage capacity has been observed. The factors that come into play are the closing up of the surface voids caused by various types of deposits, or the silting up of internal voids because of the dragging of fine materials and densification from tires rolling over the surface.

The evolution shows a great degree of dispersion and depends on conditions in the area and the type of traffic. Closing up (defined as drainage times measured with the LCS drainometer of more than 600 sec) has taken place during various periods. With the more closed porous asphalts and with the heaviest traffic (16 percent of voids in mix and more than 2,000 trucks per day and per lane), this has taken place within two years of the opening of traffic and with the more open porous asphalts and with medium traffic (about 1,000 trucks per day) after 9 years they are not totally closed up.

Sand patch depth and SFC values show no appreciable change over many years, and today all the sections constructed with these mixtures are in good condition, without any serious deterioration. Despite the decrease in drainage capacity, all the sections, including those that are closed up, remain dry in light rains or immediately after heavy rains, with a marked difference in this aspect compared to conventional dense graded mixes.

Table 5 shows the values corresponding to the evolution of drainage times for the experimental pavements of Santander with these kinds of mixes. The level of traffic on this road is 5,000 vehicles a day per lane, of which 700 are trucks. It is a rainy area used mainly for agricultural traffic. As can be seen, some of them maintain a certain capacity of drainage after 7 to 9 years. The SFC and SRC values are 0.50 to 0.60 and 0.50 to 0.70, respectively, after the same period. The sand patch depth is 1.2 to 1.5 mm.

Table 6 shows the results obtained over 4 years on a highway located near Madrid. It has a double carriageway and two lanes going in each direction, with a level of traffic of about 10,000 vehicles a day per carriageway of which 1,800 are trucks. The initial voids content was 17 percent.

TABLE 5 PERMEABILITY (SANTANDER TEST SECTIONS)

Test Section	Permeability (seg)				
	Initial	4 Months	2 years	4 Years	9 Years
I	30	75	180	288	silting up
II	46	70	100	159	220

Test Section	Permeability (Seg)		
	4 Months	2 Years	7,5 Years
2	65	180	Silting up
3	58	220	350
4	45	140	300
6	120	300	Silting up
9	80	200	Silting up

TABLE 6 PERMEABILITY (SEC) IN DIFFERENT AREAS OF THE CARRIAGEWAY (NAVALCARNERO)

LEFT LANE				RIGHT LANE			
DISTANCE TO THE EDGE OF CARRIAGEWAY MARKING (m)							
0.70		1.70		1.70		0.70	
63	79	71	87	80	113	150	219
99	-	109	-	226	608	362	988

10 - 30 measures in each point

- Not measured

KEY

6 months	1 year
2 years	4 years

The drainage time was 200 sec after 1 year in some points on this pavement and in all the right lane after 2 years. After 4 years, this lane is almost closed up. Although it has been seen that the main factor in the closing up is the postcompaction in the wheel tracks, the area between them in the slow lane is also closed up because of spillage from trucks. The left lane of the same carriageway is still in good condition.

Porous mixes with voids content >20 percent

These mixes, first used extensively in 1986, today are the most widely used. They are generally of the PA grading type, with modified bitumens in percentages in the 4.3 to 4.8 range.

The initial drainage time varies between 15 and 25 sec and the sand patch depth between 1.3 and 2.2 mm. The SFC and SRC values are 0.60 to 0.80 and 0.54 to 0.80, respectively.

The mixes tested in the experimental pavements of Santander now have, after 7 to 9 years of service, drainage times of between 150 and 300 sec.

In the Las Rozas-Villalba road (44 km), with 2,000 trucks per day per lane, the mix initially had a voids content of 22 percent and registered initial drainage times of about 20 sec. Today after 2 years, the interval of drainage time values is between 20 and 50 sec. The texture is of approximately 2.2 mm and its coefficient of skid resistance is 0.55 to 0.60 and 0.60 to 0.80 measured with the TRRL pendulum and SCRIM, respectively.

CONCLUSIONS

Porous asphalts with voids content of less than 20 percent have varied widely in their behavior. With heavy traffic, they have closed up after 2 years of use. With medium traffic, however, they have maintained their drainage capacity after 9 years. None of the pavements using this material have shown any serious deterioration. Despite reduced drainage capacities, all the pavements, including those that have closed up, show a dry appearance during light rains or immediately after a heavy rainfall. The skid resistance has been very good until now.

Porous asphalts with voids contents higher than 20 percent held up very well even under heavy traffic, although in this case the experience has only been over 3 years. As is the case with the other mixtures, these have not shown any serious deteriorations, and after several years, they maintain excellent skid resistance.

REFERENCES

1. MOPU Instrucción 6.1 y 2-IC de la D.G.C. Madrid, 1989.
2. F. E. Perez. *Permeámetro LCS*. Universidad de Cantabria, Santander, 1985.
3. *Permeabilidad in situ de pavimentos drenantes mediante el permeámetro LCS*, NLT-327/88. CEDEX-MOPU, Madrid, 1988.