A Comparison of Swiss and Japanese Porous Asphalt Through Various Mechanical Tests

Lily D. Poulikakos, EMPA
Shigeki Takahashi, Japan Highway Public Corporation, JHRI
Manfred N. Partl, EMPA

Conference paper STRC 2004

STRC 4th Swiss Transport Research Conference
Monte Verità / Ascona, March 25-26, 2004

A Comparison of Swiss and Japanese Porous Asphalt Through Various Mechanical Tests

Author:LilyD.Poulikakos
Department:RoadEngineering/SealingComponents
OrganisationEMPA
City Dübendorf

Phone: 01-823 44 79
Fax: 01-821 62 44
e-Mail: lily.poulikakos@empa.ch

Author:ShigekiTakahashi.
Department
Organisation:JapanHighwayPublicCorporation
Country: Japan

Phone: ----
Fax: ----
e-Mail: Shigeki.Takahashi@gw.jhnet.go.jp

AuthorManfredN.Partl
Department:RoadEngineering/SealingComponents
OrganisationEMPA
City Dübendorf

Phone: 01-823 41 13
Fax: 01-821 62 44
e-Mail: manfred.partl@empa.ch

Abstract

In this international co-operative research project between JHRI and EMPA, porous asphalt specimens produced by a new mix design method were compared to both Swiss and Japanese Standard mixes from conventional empirical mix designs. Different tests addressing both durability and functional properties of porous asphalt were carried out. The results of this ongoing research indicate that the new method leads, in many cases, to porous asphalt mixes with superior quality as compared to traditional standard mixes. In addition it is shown that the different test methods applied in this study generally lead to comparable results. Furthermore the mechanical properties of a standard Swiss mix have been compared to a standard Japanese mix.

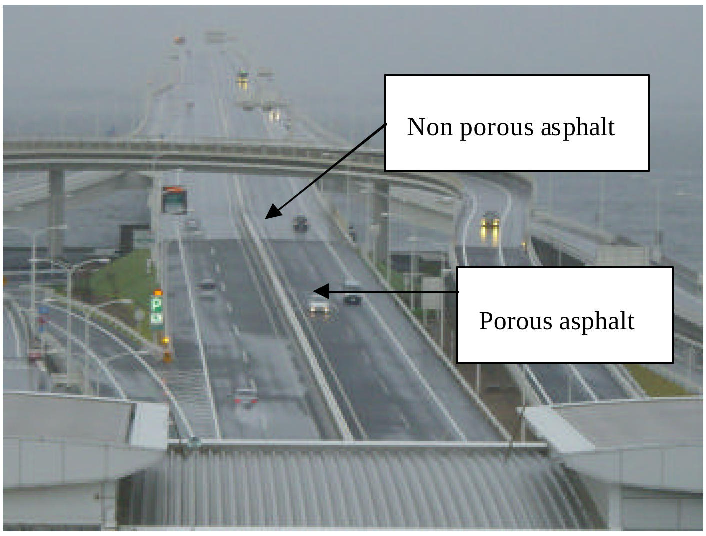
Keywords

Porous Asphalt – wheel tracking – Cantabro– Permeability – 3rd Swiss Transport Research Conference – STRC 2004 – Monte Verità

1. Introduction

Porous asphalt or open-graded asphalt is the result of **advanced technology** in pavement design. It is used in the top layers, usually has an air void content of 20% or greater, due to higher proportions of coarse aggregates and lower sand and filler content. As a result of this composition interconnected voids are created which, in wet weather, allow the surface first to absorb water like a sponge, preventing ponding on the road surface, and then leading it away, like a series of micro pipes, into a drainage system. Porous asphalt is used worldwide and offers a number of solutions to pavement problems. It is appreciated for its benefits in noise reduction and **improved safety** under wet conditions. Figure 1 demonstrates the reduction of splash and spray in a porous asphalt pavement in Japan.

Figure 1 Aqua line crossing Tokyo Bay during a rain storm



Despite the environmental benefits, porous asphalt can suffer from problems, which can affect both its performance and service life. The open structure exposes a large surface area to the effects of air and water, leading to rapid aging of the binder which in turn leads to loss of adhesion and particle loss. Over time the blockage of pores by road debris and post-compaction under traffic loads lead to loss of permeability. In order to reduce the problems associated with porous asphalt and retain the benefits, the study of porous asphalt has become an important objective within the main focus of advanced pavement materials research at EMPA. A joint Swiss-Japanese research project, presented here, has been initiated focussing on the optimization of the mineral skeleton for more durable heavy duty porous asphalt pavements. This paper concentrates on the experimental aspects of this still ongoing research.

2. Mix Design

Two mix design methods with materials from both countries were considered as given in Table 1.

Table 1 Type and notation of mixes used in this study

Mix Design Method	**Materials**	
	Japan	**Switzerland**
Traditional (Empirical)	JPA	SPA
Packing mix (Theoretical)	JPPA	SPPA

2.1 Theoretical Aggregate Gradation Mix Design Method

Both The JPPA and SPPA methods are based on a theoretical packing theory which was pioneered for dense asphalt mixes by Furnass in 1931 (1), followed by others (2, 3, 4). Later, Cabrera et al. (5) developed the DPM (Dry Packing Method) for porous asphalt by designing to a target porosity of the dry aggregates (i.e. without binder) after compaction, starting with the minimum porosity of the coarse aggregate fractions. Five aggregate size fractions A,B,C,D,E are used. In a first step, the maximum size aggregate fraction A is blended with the finer fraction B until the combination AB with minimum porosity is found. Then, AB is blended with the next finer fraction C and so forth. Finally, the finest aggregate fraction F is added until the target porosity is achieved. The DPM method was further modified by Zoorob et al. (6) by introducing the WPM (Wet Packing Method), where the aggregates are coated with bituminous binder in a mixer prior to compaction. The theoretical mix design methods are described in detail by Takahashi et al. (7) who continued this study and confirmed the advantage of the WPM for porous asphalt with a selected number of laboratory tests.

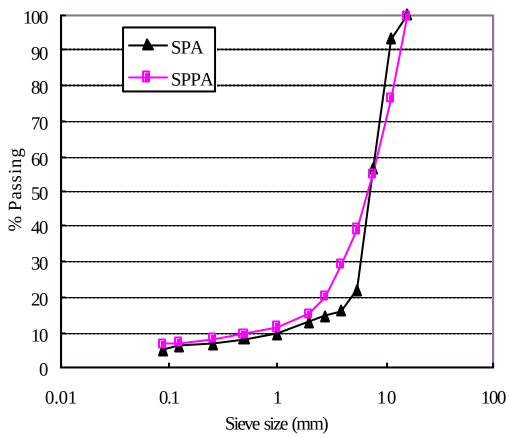
2.2 Aggregate Gradation and Binders of Different Porous Asphalt Mixes

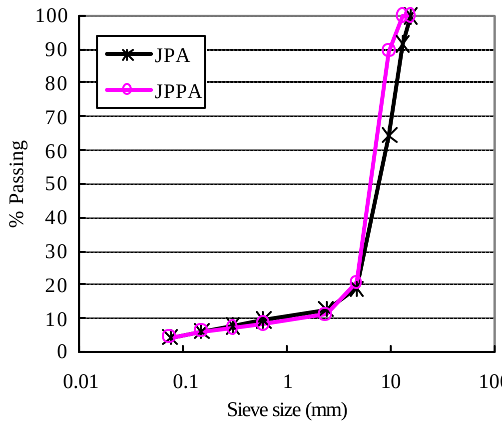
The Swiss standard porous asphalt (SPA) from the A1 motorway in Canton Aargau was compacted by the Superpave Gyratory Compactor (SGC) and Marshall compactor and used to compare the mix properties to the theoretically packed SPPA. The gradations of those two mixes are presented in Figure 2. Both gradations have the same target porosity of around 22% by volume. The mineral stone used in the SPA consisted of a combination of siliceous limestone and crushed gravel from the river Rhine. The mineral aggregates for the SPPA specimens were of crushed hard grid stone from a quarry in Kitzbühel Austria. The recovered binder of 4.8% by mass from SPA was a 50/70 penetration graded straight run bitumen with Trinidad NAF 501. For the SPPA, 4.1% by mass of Styrelf 13/80 penetration graded SBS polymer modified bitumen (PmB-C 50/70-53) was used. On the other hand, both Japanese mixes JPA and JPPA with the same target porosity of 23% and the gradation curves shown in Figure 2 use the same aggregates (hard sand rock) and polymer modified bitumen with 9% SBS. A comparison of binder properties is shown in Table 2.

Table 2 Binder test results

Property	JPA and JPPA	SPA	SPPA
Penetration 1/10 mm	45	15	50
Ring and Ball °C	90.1	80.7	56.5

Figure 2 Swiss (left) and Japanese (right) porous asphalt gradations.





3. Test Procedure and Discussion of Results

Several industry standard tests were carried out to compare performance related properties of both theoretically and empirically designed porous asphalt specimens. Namely laboratory aging of mixes, Cantabro (particle loss), water permeability, binder penetration, binder softening point, rheology of the binder using the dynamic shear rheometer (DSR), interlayer shear strength, indirect tensile, shear modulus of mixes using the Coaxial Shear Test (CAST), special to EMPA, and wheel tracking, This paper focuses on the results of a selected group of tests indicated above.

3.1 Laboratory Aging of Mix

The mixes at EMPA have been short term (STOA) and long term (LTOA) aged according to the guideline in [9]. Short term aging simulates the pre-compaction phase of the construction phase, and long term aging simulates aging over the service life of the pavement. In the first step, for STOA, laboratory prepared loose mix asphalt was placed in a pan and conditioned in a forced draft oven for 4h±5 minutes at the mix compaction temperature. Thereafter, for LTOA, the loose mix from STOA was used to prepare the specimens which were then aged in a forced draft oven at 85±3°C for 120±0.5h. All specimens were un-moulded before the LTOA except the wheel tracking specimens, which were aged with the mould in order to minimize specimen size alteration during aging. At the conclusion of LTOA, binder run down could be visually observed. Although some binder run down can be expected in situ under hot weather it's extent in these laboratory samples exceeded the in situ expected run down. The results indicated that due to high porosity of the material, LTOA is not an optimal procedure for porous asphalt.

3.2 Porosity

All JHRI specimens were produced in the SGC, at an appropriate compaction temperature depending on the binder type. After compaction to target porosity, 204 extra gyrations were applied at 60 °C to simulate over-compaction from traffic loads. In order to calculate the porosity of each mix before and after over-compaction the height of the specimen was measured by callipers. The change in porosity before and after over-compaction is shown in Figure 3. Both

JPA and JPPA maintained a higher porosity after over-compaction than SPA and SPPA. The reason may lie in the binder viscosity and binder content differences, emphasizing the important contribution of the binder to the mechanical resistance of porous asphalt. Contribution of theoretical packing theory, however, is shown in JPPA. This mix kept comparatively higher porosity than JPA after over-compaction. SPPA did not show good resistance to over-compaction.

3.3 Water Permeability

A constant water head type permeameter, a Japanese standard laboratory equipment and procedure, was used in this study. Vertical water permeability of the SGC specimen was measured before and after over-compaction. Figure 4 summarizes the result. Initially, SPA had a significantly higher water permeability than the other mixes. After over-compaction, SPA and both Japanese mixes showed similar permeability levels. The initial theoretical SPPA and JPPA mixes did not show an improvement in water permeability. However, an improvement in resistance to over-compaction can be seen from the behaviour of JPA vs. JPPA in Figure 3 even though the water permeability in over-compacted state remains the same.

Figure 3 Porosity of porous asphalt mixes with different gradations before/after over-compaction

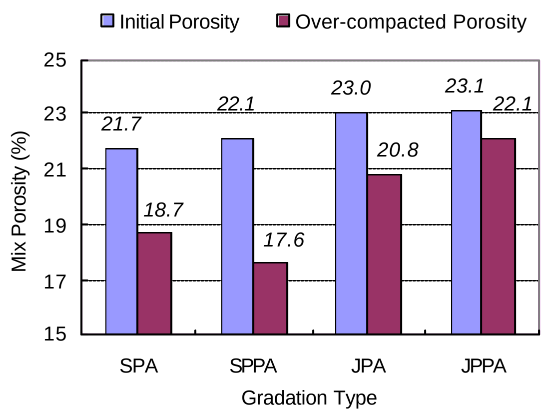
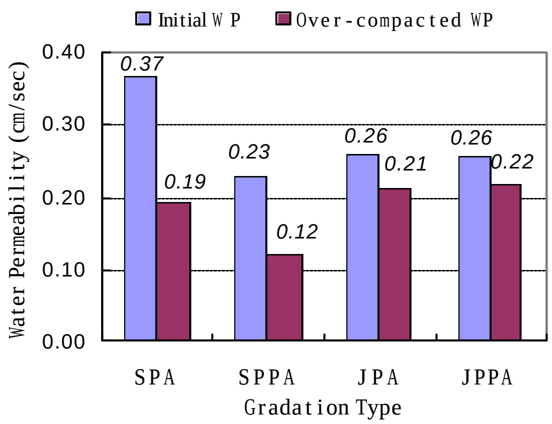


Figure 4 Water permeability of porous asphalt mixes with different gradations before/ after over-compaction.



3.4 Wheel Tracking Tests

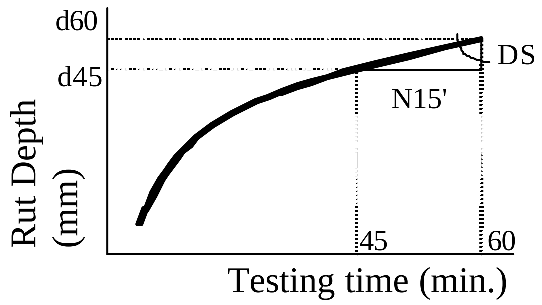
Two types of wheel tracking tests were used. In the JHRI type of test, a steel roller is used to compact a loose mix with 294 N/cm and 25 load cycles at compaction temperature in a 300mm square and 50mm deep mould. Next, the compacted specimen is set at 60 °C under

686 N repeated loading at 42 passes/min by a special solid rubber tire (200mm diameter and 50mm width) for 1 h. From the measured rut depth d the dynamic stability DS is calculated by the following formula.

DS [passes / mm] = N15'/ (d60 – d45)   (1)

Where N15' stands for the loading passes, i.e. N15' = 15[min] x 42 [passes/min], and d60-d45 for the change in rut depth in the last 15 minutes of the test. Consequently, higher DS values mean better rut resistance at 60 °C.

Figure 5   Definition of DS, wheel tracking test.



Both JPA and JPPA performed well in the JHRI wheel tracking tests. This can be attributed to the Japanese binder. The JHRI recommendation for dynamic stability of mixes experiencing light and medium traffic volume is DS = 800, and DS = 3000 for heavy traffic highways. As shown in Figure 6, the dynamic stability, DS, of SPA is above those recommended by JHRI for light and medium traffic. No significant contribution of the theoretical packing can be seen in this type of wheel tracking test. The low DS value of SPPA is consistent with its susceptibility to over-compaction as discussed in Figure 3.

Another type of wheel tracking test developed by LCPC was conducted at EMPA. The mix was compacted with a steel roller in a steel mould (100 x 180 x 500 mm). During the rutting test at 60 °C, the specimens are loaded in cycles of 1Hz by a tread-less pneumatic rubber tire (400mm diameter and 80mm width) with a contact loading pressure of 5.05bar (505kPa). Figure 7 presents the results from EMPA. Additionally, aging effects as defined in section 3.1 were studied in this test. Although in the unaged state a difference could be seen in the rutting performance of the four mixes, no difference was observed on aged specimen. The theoretical mix JPPA showed an improvement to JPA in the unaged state.

Figure 6 Mix porosity of porous asphalt mixes with different gradations before/after over-compaction. (JHRI)

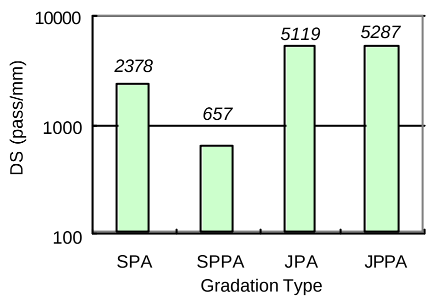
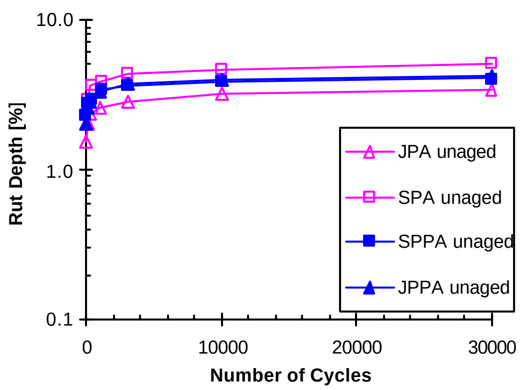
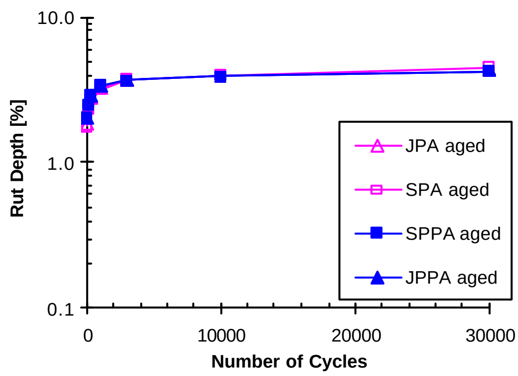


Figure 7 Rut depth of porous asphalt mixes with different gradations in LCPC wheel tracking test for unaged (left) and aged (right) specimen (EMPA).





3.5 Indirect Tensile Tests

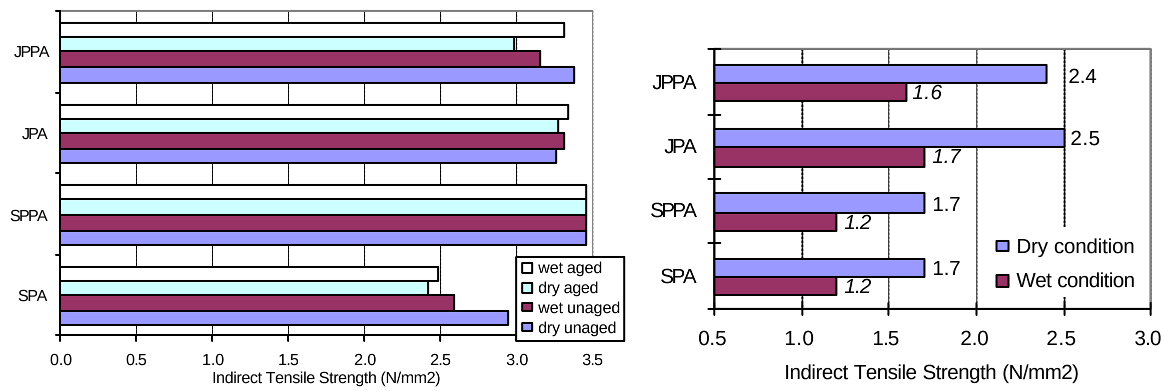
The indirect tensile test was used to determine tensile strength of porous asphalt specimens by both JHRI and EMPA. The specimens were tested after preconditioning in water and or a temperature-controlled chamber. The purpose of the indirect tensile test in this investigation is to assess the resistance to thermal cracking at low temperatures. Hence the test temperature was decreased to 0°C to simulate roads in winter.

At JHRI, to evaluate water sensitivity of the mix, tests were conducted in both dry and wet condition. Wet conditioning of the specimen were conducted for 48 h in a 60 °C water bath, corresponding to the same conditioning method as in the immersed Marshall test in Japan. Loading was applied to the SGC specimen (∅=150 mm) with a speed of 50 mm/min at 0 °C.

At EMPA, Marshall specimen (∅=100 mm) from both unaged and aged material were prepared. Thereafter the specimen were long term aged in accordance with section 3.1. Three aged and unaged specimens per mix were conditioned in an air chamber and in a water bath for 24 h at 20 °C. After conditioning, all specimens were further conditioned in an air chamber at 0 °C for another 24 hours before being tested immediately at a controlled speed of 50.8 mm/min.

Both results are given in Figure 8. According to the JHRI test results, JPA and JPPA show higher tensile strength than the SPA and SPPA in both dry and wet conditions. No significant difference appeared with respect to water sensitivity among the four gradations. Apparently, water conditioning and aging had a significant effect on the performance of SPA. The results suggest that in the case of SPA the binder aging property and it's resistance to effects of water on the binder adhesion were comparatively poor. SPPA showed a significant increase in tensile strength to SPA. The effect of the theoretical packing theory can be seen by comparing JPA and JPPA. JPPA showed some improvement in the dry unaged state only and no improvement in the wet aged state.

Figure 8 Tensile strength of porous asphalt mixes at EMPA (left) and JHRI (right)



3.6 Interlayer Shear Test

This method is used to analyze interlayer adhesion between porous asphalt wearing and base course. EMPA has modified a Layer Parallel Direct Shear (LPDS) test device (cf. Figure 9), which was originally developed in Germany [8]. The direct shear until failure is applied at a controlled speed of 50.8 mm/min at 20 °C.

Figure 10 summarizes the results, where, the mixes fall into the following categories: MIU=mix initial unaged, MPU=mix post compacted unaged, and MPA=mix post compacted aged. SPA and SPPA showed an overall better behaviour in interlayer shear strength. SPPA showed an improvement over SPA. However this cannot be attributed to the theoretically packed mix since JPPA did not show a similar improvement rather this can be attributed to the binder properties.

Figure 9 Schema of LPDS test device

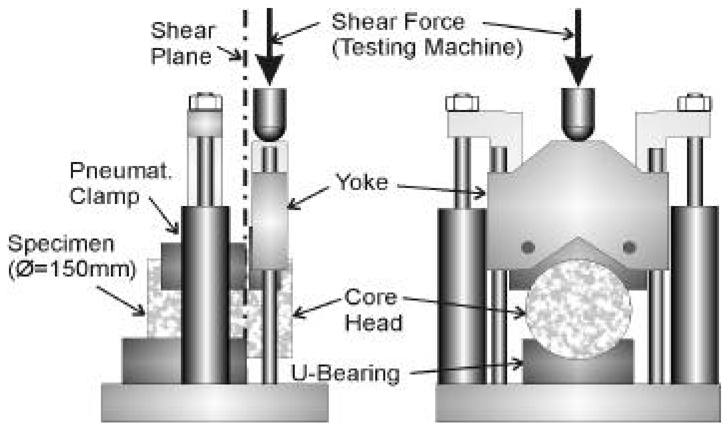
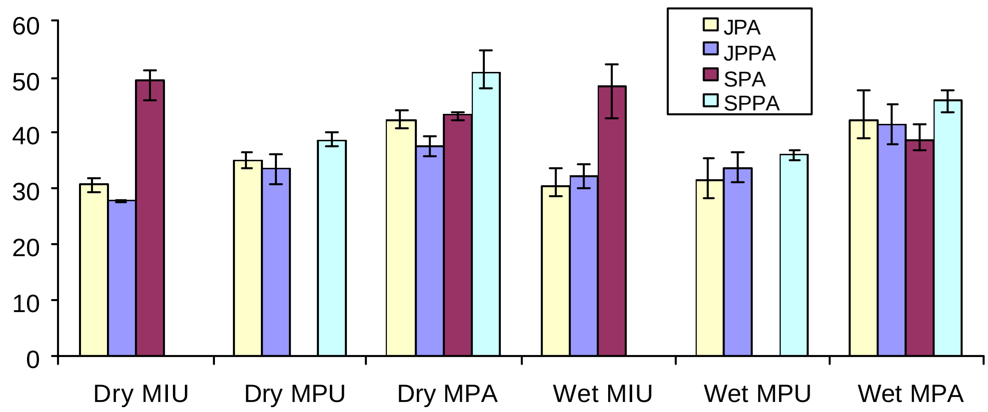


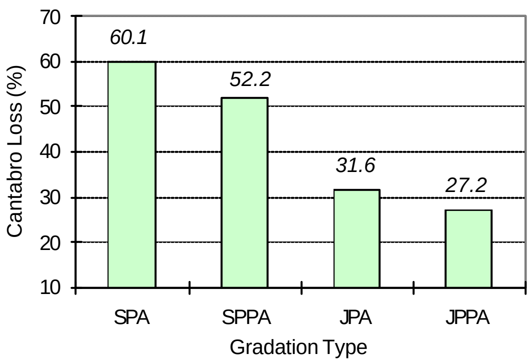
Figure 10 LPDS shear strength between porous asphalt and base course. Tests at EMPA.



3.7 Cantabro Test

Cantabro is a special test for porous asphalt to evaluate the resistance to particle loss by abrasion and the effect of impact. Cantabro loss is used as an important indicator for bonding properties between aggregate and bitumen. In this study, the specimens were conditioned at –20 °C before the test. This method is now commonly used in Japan to evaluate the particle loss resistance of porous asphalt under winter conditions. In the Cantabro test, the SGC specimen was put into a Los Angeles drum without any steel ball, and then given 300 rotations with the speed of 30…33 rpm. The specimens were weighed before and after the rotations, then the weight loss was calculated (Cantabro loss value). As shown in Figure 11, theoretical design of the two mixes, SPPA and JPPA performed better than SPA and JPA respectively. These theoretically packed mixes successfully reduced Cantabro loss by approximately 14 % compared to the empirically designed mixes. In addition, the Japanese mixes showed smaller particle loss than the Swiss ones. This can be attributed to the low temperature behaviour of the Japanese binder.

Figure 11 Cantabro loss value



4. Summary

Different tests concerning both durability and functional properties of porous asphalt were carried out. While direct results of the theoretically packed mix are apparent from comparison of JPA and JPPA, the comparison of SPA and SPPA allows the comparison of an actual Swiss mix with one that is produced in the laboratory using the theortically packed mix design. The positive effects of the packing theory can be clearly observed from the results of JPA and JPPA since exactly the same type and amount of binder was used. JPPA showed better resistance against over-compaction than JPA. The clearest advantage of the theoretical mixes was observed by the Cantabro test. Both SPPA and JPPA decreased in Cantabro loss value, compared with SPA and JPA respectively. However, the binder viscosity and binder content differences, emphasized the important contribution of the binder to the mechanical resistance of porous asphalt.

The results of this ongoing research indicate that the new method leads, in many cases, to porous asphalt mixes with superior quality as compared to traditional standard mixes, provided that the influence of the binder is considered accordingly. In addition, it is shown that the different test methods applied in this study generally lead to comparable results.

5. References

1. Furnass C.C., 'Grading Aggregates. Mathematical Relations for Beds of Broken Solids of Maximum Density', Industrial and Engineering Chemistry Vol. 23, 1931, pp. 1052-1058.
2. Goode J.F. and Lufsey L.A., 'A New Graphical Chart for Evaluating Aggregate Gradation', Proc. AAPT, Vol. 31, 1962, pp. 176-207.
3. Hudson S.B. and Davis R.L., 'Relationship of Aggregate Voidage to Gradation', Proc. AAPT, Vol. 34, 1965, pp. 574-593.
4. Lees G., 'Rational Design of Aggregate Gradings for Dense Asphaltic Composition', Proc. AAPT, Vol. 39, 1970, pp. 60-90.
5. Cabrera J.G. and Hamzah M.O., 'Aggregate Grading Design for Porous Asphalt', Proc. Performance and Durability of Bituminous Materials Symposium, University of Leeds, March 1994, pp 10-22.
6. Zoorob S.E., Cabrera J.G. and Takahashi S., 'Effect of Aggregate Gradation and Binder Type on the Properties of Porous Asphalt', Proc. 3rd European Symp. Performance and Durability of Bituminous Materials and Hydraulic Stabilised Composites, University of Leeds, April 1999, pp 145-162.
7. Takahashi S. and Partl M.N., 'Improvement of Mix Design for Porous Asphalt', Int. J. of Road Materials and Pavementg Design, volume 2 No. 3, 2001, pp 283-296.
8. Partl M.N. and Raab C., 'Shear Adhesion between Top Layers of Fresh Asphalt Pavements in Switzerland', Proc. 7th Conference on Asphalt Pavements, South Africa, 1999.
9. Standard Conditioning Practice for Hot Mix Asphalt (HMA), AASHTO Provisional Standards, 2001 edition.