Evaluation and Further Development of Porous Asphalt Pavement with 10 Years Experience in Japanese Expressways

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ABSTRACT: The NEXCOs introduced the first porous asphalt pavement in 1989 and the pavement became the standard surface course in 1998. Since then, total area of the pavement accounts for about 65% of whole surface course and the durability and function of the pavement were searched. The durability for flow rutting of the porous asphalt pavement is much better than dense graded asphalt pavement. The durability for raveling of the porous asphalt pavement is almost same as that of dense graded asphalt pavement but still needs to be improved. The fatality rate was reduced drastically after the porous asphalt was paved and the noise level was about 3 dB less than dense graded asphalt pavement. The stripping of binder course due to the penetrated water during long term is reported recently and the improvement of waterproofing property and invention of efficient diagnosis method were made. Finally, for the environment protection, the plant recycling technology was studied and the recycled porous asphalt mixture with 50% reclaimed aggregates was proved to have almost same durability as the virgin asphalt mixture.

KEY WORDS: Porous asphalt, durability, function, water-proofing, recycling

1 INTRODUCTION

East, Central, and West Nippon Expressway Company Limited (NEXCO) operate toll expressways all over Japan and introduced the first porous asphalt pavement in 1989 to reduce traffic accidents during rain. Improving the mix design and materials, the area of pavement had been increased and deployed at dangerous sites like bad alignment and specific spots in wet condition. In 1998, the pavement became a standard surface course and has reached about 65% of whole surface course on expressways nowadays.

Since the porous asphalt pavement became a standard surface course and 10 years has passed improving safety and environment, the durability and function of the pavement were evaluated and further development to solve new subjects like recycling is also described in this paper.

2 MIX DESIGN AND MATERIALS

2.1 Mix design

The target air void ratio of porous asphalt mixture is about 20% to satisfy both drainage function and durability based on the intensive laboratory tests and researches of pilot test sections on expressways. In snowy and cold region, the target is about 17% to improve durability of the pavement against raveling.

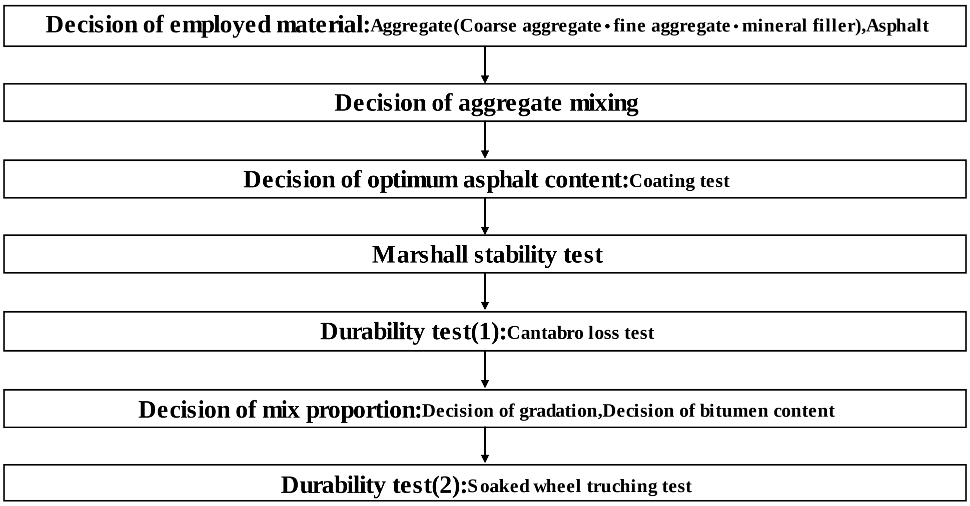
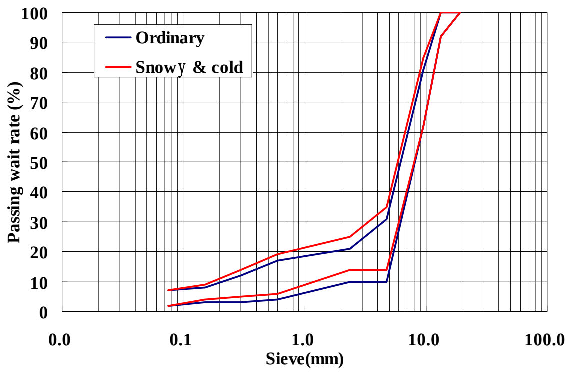


Figure1: Flow chart of mix design for porous asphalt mixture

The flow chart of mix design is shown in Figure1. The amount of asphalt binder is decided through the Marshal Stability Test and the Draindown Loss Test. In the Draindown Loss Test, five specimens which changes 0.3% of asphalt binder amount respectively are used to measure those loss amount on test pans and determine the optimum asphalt amount. For the durability evaluation, the Cantabro Test and the Soaked Wheel Tracking Test are applied. The Soaked Wheel Tracking Test is particularly applied to evaluate anti-stripping property of the mixtures in wet condition.

2.2 Materials

2.2.1 Aggregate



Sieve(mm)	Passing wait rate (%)	
	Ordinary	Snowy & cold
19.0	100	100
13.2	92～100	92～100
9.5	62～81	62～85
4.75	10～31	14～35
2.36	10～21	14～25
0.6	4～17	6～19
0.3	3～12	5～14
0.15	3～8	4～9
0.075	2～7	2～7

Figure2: Standard gradation of aggregate

Figure2 shows the standard gradation of aggregate for the mixture and coarse aggregate accounts for about 85% of whole aggregate. The abrasion property and shape of coarse aggregate particularly affect the durability of pavement and standard property of the coarse aggregate is shown in Table1

Table1: Standard property of coarse aggregate

Items	Criteria
Apparent density (g/cm^3)	**2.5**
Water absorption (%)	**≦3%**
Los Angeles abrasion loss (%)	**≦20%**
Soundness (%)	**≦12%**
Soft particles in coarse aggregate (%)	**≦5%**
Content of slender aggregate and flat aggregate (%)	**≦15%**
Stripping (%)	**≦15%**

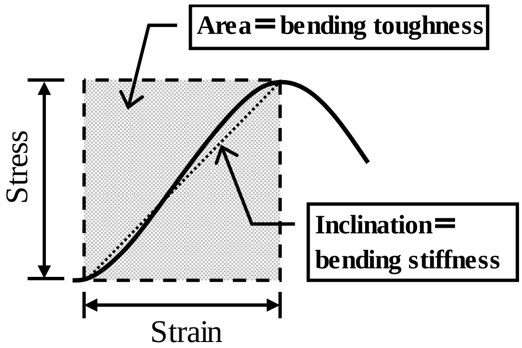


Figure3: Interpretation of bending test result

2.2.2 Asphalt binder

In order to prevent raveling or deformation of the porous asphalt pavement, High Polymer-Modified Asphalt (HPMA) became the standard binder. The HPMA binder contains about two times of polymer compared with ordinary polymer-modified asphalt. The polymer consists of mainly SBS (Styrene-Butadiene-Styrene block polymer). The HPMA binder is extremely cohesive and the Toughness & Tenacity Test applied for the ordinary polymer-modified asphalt binder was not suitable. The Bending Test for asphalt mortar beams was studied to evaluate the property of HPMA binder (Takahashi et al.2002). The interpretation of the bending test result is illustrated in Figure3.

Table2: Standard property of HPMA binder

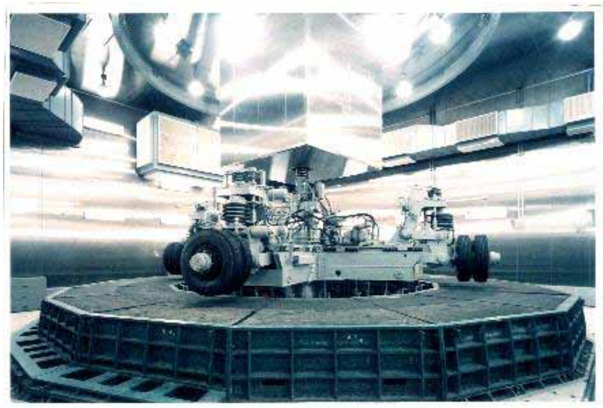
Items	Ordinary	Snowy & cold
bending toughness (-20℃) ×10^{-3} MPa	**≧100**	**≧750**
bending stiffness (-20℃) MPa	**≦450**	**≦80**

In Table2, the standard property of HPMA binder for both ordinary area and snowy & cold area is shown. The test temperature of – 20℃ gave the most sensitive changes of the bending toughness in proportion to the change of the polymer amount. A test shows 1% change of polymer amount leads to about 50(x10^{-3}MPa) change of bending toughness.

2.3 Durability of porous asphalt pavement

The result of durability test by the accelerated pavement test machine and pilot sections on expressways are reported here.

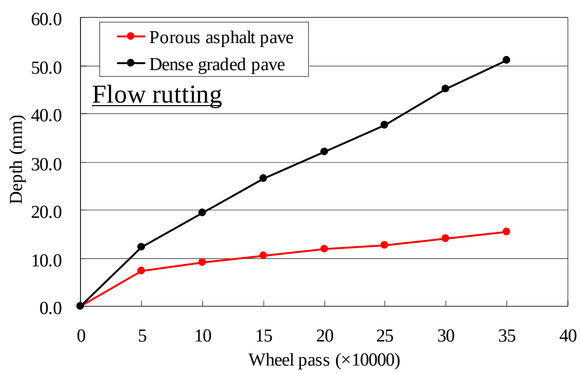
2.3.1 Accelerated pavement test



Diameter	8m (Inside)
	10m (Outside)
Lord	0~7t/Wheel
Speed	Max 100km/h
No. of test piece	16piece/Ring
Tires	Heavy truck double
	Heavy truck single
	Passenger
Shift account	Max ±200mm
Wet condition	Possible

Picture1: Outline of the accelerated pavement test machine

The NEXCO research institute's accelerated pavement test machine has the feature shown in Picture1 and plays very important role to evaluate the durability of pavements in short time before trials of new type of pavement on expressways.



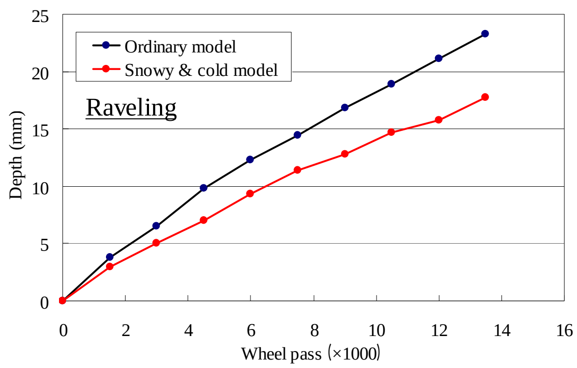


Figure4: The result of flow rutting test and raveling test

Figure4 (left) shows the result of flow rutting test (Surface Temp. 60℃, Load 49kN/wheel) and porous asphalt pavement demonstrates less flow rutting depth than dense graded asphalt pavement. The result attributes to the combination of HPMA binder and much distribution of coarse aggregate in the gradation.
Figure4 (right) shows the result of raveling test (Surface Temp. 0℃, Load 49kN/wheel, chain wearing) on the test pieces with different asphalt binders, one for ordinary area and another for snowy & ice area described in Table2. The deformation on test pieces with asphalt binder for snowy & ice area demonstrates about 30% less raveling depth than that of pieces with binder for ordinary area.

2.3.2 Research result of durability on expressways

The result of deformation research during 60 month is shown in Figure5. The deformation of porous asphalt pavement in ordinary area has increased about 1 mm/year and been less than dense graded asphalt pavement. The result of porous asphalt pavement in snowy & ice area is demonstrated less than dense graded asphalt pavement but more than porous asphalt pavement in ordinary area. Though the air void ration and property of the HPMA binder in snowy & ice area have been improved, the raveling still seems to give much damage on the pavement surface in winter.

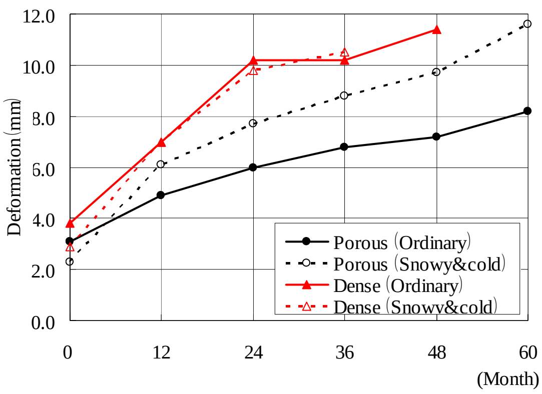


Figure5: Changes of deformation in different areas

3. STATUS OF SAFETY AND ENVIRONMENT

3.1 Safety

One of the worth feature of the porous asphalt pavement is drainage function which leads to improve safety in wet condition and that made NEXCOs enthusiastically introduce the porous asphalt pavement on expressways.

At the first stage, the porous asphalt pavement was introduced in sites with high accident rate in rainfall due to mainly the bad alignment of expressways and then, the porous asphalt pavement has been increased over nationwide expressways as a standard surface course.

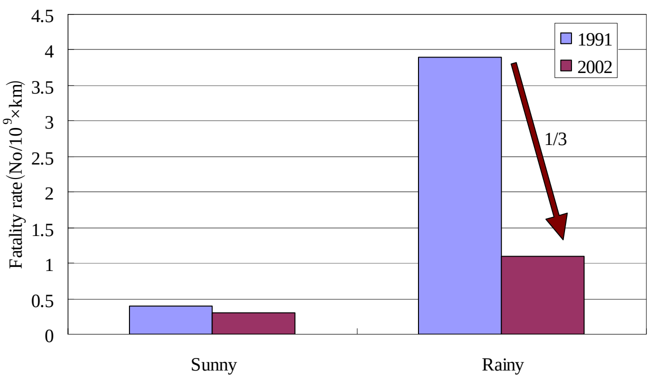


Figure6: Change of fatality rate

Figure6 shows the fatality rate at same sites of expressways before (1991) and after (2002) the porous asphalt was paved and the rate was decreased by about two third. The better visibility and high skid resistance of the porous asphalt pavement attribute to the result. In Figure7, the average skid resistance of porous asphalt pavement has high skid resistance compared with dense graded asphalt pavement, and concrete pavement on expressways. The skid resistance was measured by the wheel-locked type measuring vehicle at 80 km/h.

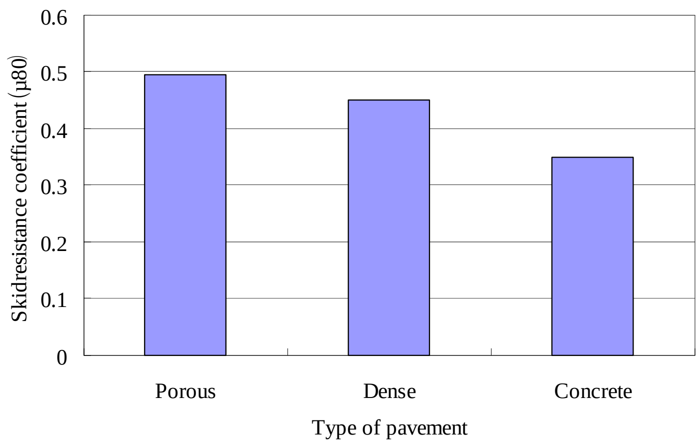


Figure7: Skid resistance of different surface type

3.2 Noise reduction

The porous asphalt pavement also has the noise reduction function and many researches were done to detect the noise reduction effect and how long the effect would be kept.

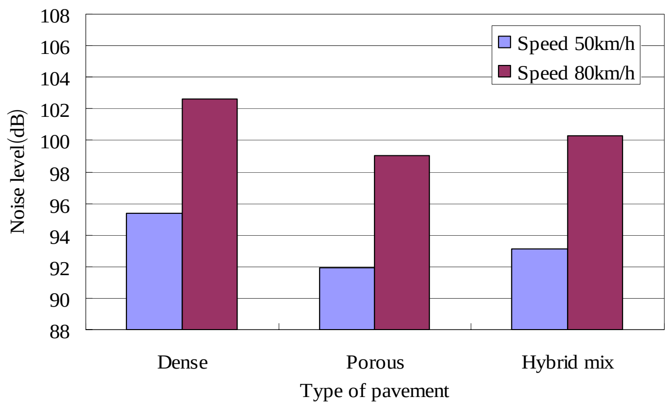


Figure8: Noise level of different surface type

The noise generated by interaction between tire and pavement surface was measured on expressways which were just after construction. The microphone was equipped near tire to catch the noise directly with different speed on different type of pavement and the result is shown in Figure8. The noise level of porous asphalt pavement is about 3 dB less than that of dense graded asphalt pavement at the different measuring speed respectively.
Another study reports that the sound power level of passenger vehicle on porous asphalt pavement on expressways after construction is about 6dB less than that of dense graded

asphalt pavement and the power level deteriorates 0.5dB annually (Ueta et al. 2009).

4. STRIPPING OF BINDER COURSE AND COUNTERMEASURES

4.1 Stripping of binder course

In accordance with the increasing stock of porous asphalt pavement on expressways, pumping phenomena and partial deformation of pavement due to the penetrated water and traffic loads in long term have been observed gradually. Picture2 shows the typical pumping phenomenon on the porous asphalt pavement which the segregated asphalt binder and soil appear on the surface.

Picture2: Phenomenon of pumping damage

4.2 Diagnosis method of the binder course stripping

To evaluate and diagnose the stripping of binder course effectively, a new method using the Accelerated Permeability Test was developed. First, the specimens derived from cores taken from damaged binder courses on expressways are pressed under the hot water (60℃) promptly in the Accelerated Permeability Test and then, measured the remaining splitting strength as the residual stress. The splitting strength measured specimens from the law cores taken from same site of expressways is used as the standard splitting strength. Combined with the test results and our observation of stripping in the sites, the diagnosis chart shown in Figure9 was invented. If the remaining splitting strength is plotted under the red line in Figure9, the binder course is diagnosed to be stripped (Motomatsu et al. 2004).

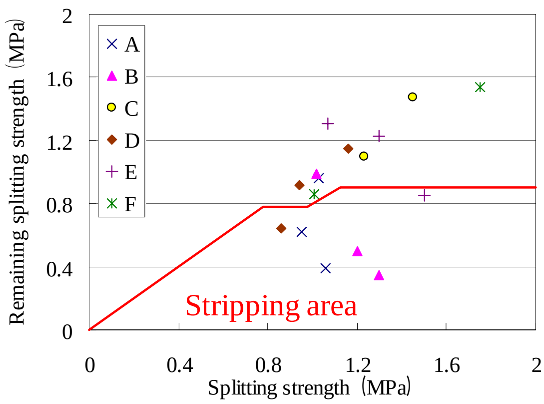


Figure9: Chart for judgment of stripping

This diagnosis method has worked well so far and been comparatively accurate; however, it consumes much time to complete the whole test process. Therefore, another method which uses the deflection measured by FWD (Falling Weight Deflectometer) has been studied to evaluate the possibility of the stripping (Kamiya et al. 2008).

4.3 Improvement of waterproofing property of binder course

Coarse graded asphalt mixture is used for the binder course and the air voids and saturation degree in the standard property were modified to improve the waterproofing property when the porous asphalt pavement became the standard surface course about 10 years ago. The polymer modified asphalt binder or stone mastic asphalt mixture is also used in the binder course to improve waterproofing property in some cases.

Recently, the stripping ratio for the binder course (less than 5%) by the Soaked Wheel Tracking Test was introduced to improve the waterproofing property further. The concept of the Soaked Wheel Tracking Test is shown in Figure10.

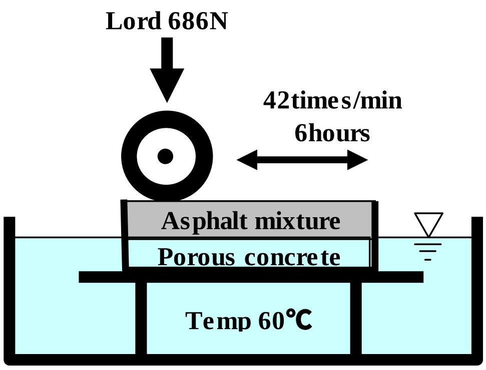


Figure10: Concept of Soaked Wheel Tracking Test

5. DEVELOPMENT OF RECYCLING TECHNOLOGY

The porous asphalt pavement accounts for about 65% of whole pavement on expressways and repaving of porous asphalt pavement have begun recently. The amount of repaving the porous asphalt pavement will increase drastically in the near future and the recycling technology for the porous asphalt pavement is indispensable to protect environment.

5.1 Plant recycling technology

The process of recycling technology at plants for porous asphalt pavements is followings, a) to transport milled asphalt pavement debris into asphalt plant for recycling, b) to crash the debris and adjust the gradation, c) to add reclamation materials and fresh asphalt binder, d) to mix adjust materials in mixer, and e) to transport the recycled porous asphalt mixture to sites and pave. The mix design method and evaluation method of recycled porous asphalt mixture have been studied and the technologies are completed to apply maintenance works on expressways.

5.1.1 Mix design method

The original asphalt binder of porous asphalt mixtures in the pavement on expressways is the High Polymer-Modified Asphalt Binder and it is difficult to extract and evaluate the property of aged asphalt binder. Therefore, the amount of reclamation materials and fresh asphalt binder for the recycled mixture is decided by the Draindown Test and Marshal Stability Test, and then, the Cantbrou loss ratio of the reclaimed mixtures is used to decide whether the amount of reclamation materials and fresh asphalt binder are satisfied with same durability specification as the virgin porous asphalt mixture has.

In the laboratory test, the maximum ratio of the recycled aggregates in whole recycled asphalt mixture was 50% to satisfy the durability target. The process of recycling mix design is shown in Figure11.

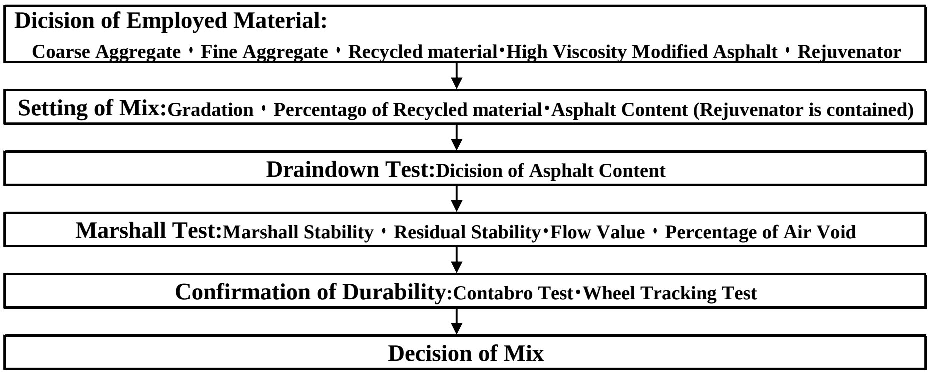


Figure11: Flow chart of recycling mix design

5.1.2 Durability of the recycled asphalt mixture

The accelerated pavement test was conducted to evaluate durability of the recycled asphalt mixtures. In the first stage, durability for raveling was observed with the condition of surface temperature (Temp.) 20°C and Load 49kN. Durability for flow rutting was also observed with the condition of Temp. 53°C and same load in the second stage of the test. The result is shown in Figure12 and the recycled aggregate 50% means the recycled aggregate account for 50% of whole aggregate. The A, B, and C mean different type of reclamation materials.

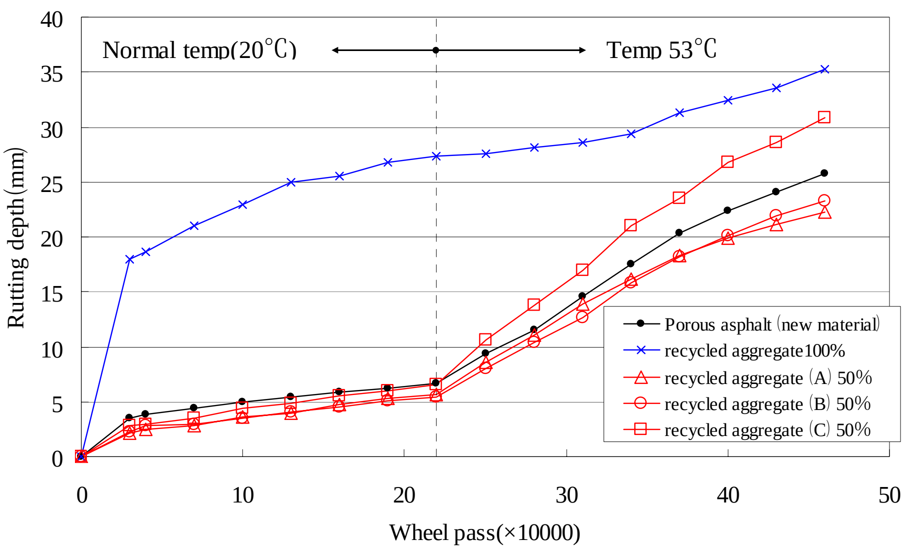


Figure12: The result of raveling and flow rutting test

In the Figure12, it is clear that 100% reclaimed asphalt mixture is significantly less durable than the virgin asphalt mixture and 50% recycled asphalt mixtures have almost same durability as the virgin asphalt mixture.

6. CONCLUSIONS

Since the porous asphalt pavement became the standard surface course on expressways, 10 years have passed. Based on our research, following things were clarified.

1) Regarding the durability for flow rutting, the porous asphalt pavement is much better than the dense graded asphalt pavement. Though the durability for the raveling of the porous asphalt pavement is almost same as the dense graded asphalt pavement, it still needs to be improved. The mix design method and standard properties of material have been proper as a whole.
2) The fatality rate in the rainfall was reduced drastically after the porous asphalt was paved. The better visibility and high skid resistance attribute to the improvement of safety.
3) The noise of the porous asphalt pavement is about 3 dB less than that of dense graded asphalt pavement. The noise reduction function is kept comparatively longer.
4) The pumping phenomenon is reported recently due to the stripping of binder course by penetrated water during long term. The stripping ratio by the Soaked Wheel Tracking Test was introduced to improve the water-proofing property and new diagnosis method was invented to evaluate the stripping accurately and efficiently.
5) For the environment protection, the plant recycling technology for the porous asphalt pavement was studied. Under the developed mix design method, the 50% recycled asphalt mixture has almost same durability as the virgin asphalt mixture.

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