An Innovative Recycling Method of Porous Asphalt for the Japanese Motorways

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ABSTRACT: Currently over 70% of road surface in the Japanese motorways are covered with porous asphalt, and recycling of the pavement has become a big social responsibility. However it has been technically concerned because of its open gradation and modified bitumen with higher SBS contents; the milled materials cannot be well mixed again in recycling plants like other dense materials. One more recycling issue to consider is a peculiar distress of underlying binder layer being weakened under immersed condition in wider ranges of temperature in Japan. Thus two layers need to be recycled at a time. For the purpose of fully recycling the two layers materials, possibility of a satellite recycling plant being tentatively built nearby the site together with in-site surface recycling for binder layer was studied. First entire porous layer and part of binder layer are milled and shipped to the satellite plant. The materials are then divided into two sizing: 13-5mm for recycled porous mix and 5-0mm for recycled binder mix to be added for the surface recycling. Recycled binder mix is designed to have impermeability and sufficient dynamic stability, while recycled porous mix to have 17% air voids and sufficient raveling resistance. After laboratory tests and Accelerated Pavement Testing, porous mix rejuvenated with 80% recycled materials shows porosity and durability the same level as new materials. In-site and recycled binder materials rejuvenated also shows impermeability and sufficient strength required. Finally it was confirmed in a repair project that the satellite plant system with surface recycling enables a direct porous to porous recycling as well as binder layer's improvement.

KEY WORDS: Porous asphalt, satellite plant, in-site recycling, binder layer, rejuvenator

1 INTRODUCION

The Japanese nationwide toll motorways with total length of approximately 8500km are now being operated by three companies, namely East, Central and West Nippon Expressway Company, (hereafter called NEXCO). For upgrading safety on wet road surface, porous asphalt has been widely implemented all over NEXCO as standard road surface since 1998. Currently the pavement shares approximately 70% of the roadways under NEXCO. Because porous asphalt is becoming aged over 10 years, recycling of the pavement is a big social responsibility for NEXCO as toll road operators.

According to a past study on recycling of porous asphalt, however, several technical issues were pointed out (Matsumoto et al. 2004). The most fundamental point for remixing at plant is how to deal with its peculiar gradation and highly modified bitumen with SBS content of 8% or higher. Existing materials of which 13-5mm is adjusted at plant are recyclable, while the other 5-0mm are mostly of no use. In addition bitumen mortar even after adjusting the aggregate size is very sticky inside the recycling drier.

In order to practically solve these technical problems, a joint study has been carried out for two years by formulating both knowledge from road operator and paving contractor, respectively between NEXCO Expressway Research Institute and Kajima Road Co. Ltd. This paper reports findings from an innovative recycling method of porous asphalt, based on a satellite plant system being tentatively built nearby the site together with in-site surface recycling for binder layer.

2 TARGET LAYERS

In addition to stripping of aggregates and potholes in snowy and cold regions as is indicated in overseas countries (DRI-DWW, 2006), there have been unfamiliar underlying layer based problems. Photo 1 shows serious scaling and abrasion in a snowy section, while Photo 2 does blowing up of particles of the underlying binder layer’s mixture, which was stripped by remained water on the binder layer all over Japan (Kamiya et al. 2008). The reason why the latter is a popular distress is due to wider temperature ranges and higher annual rainfall in Japan, compared with overseas countries.

Photo 1: Scaling and abrasion in a snowy section

Photo 2: Particles blowing up from Porosity

This underlying layer based problem that requires higher repair costs is concerned on increase, since most of the sections have been replaced only with porous layer, while the underlying binder layer remains not replaced with new materials.

Consequently repairing two layers at a time is now becoming a general procedure of porous asphalt, and thus structural design for the porous to porous recycling also needs to follow this condition, that is two layers to be recycled at a time in this joint study.

3 CONCEPT OF RECYCLING SYSTEM

For the purpose of fully recycling the two layers materials, possibility of a satellite recycling plant being tentatively built nearby the site together with in-site surface recycling for binder layer was studied. Figure 1 shows the concept of the recycling system.

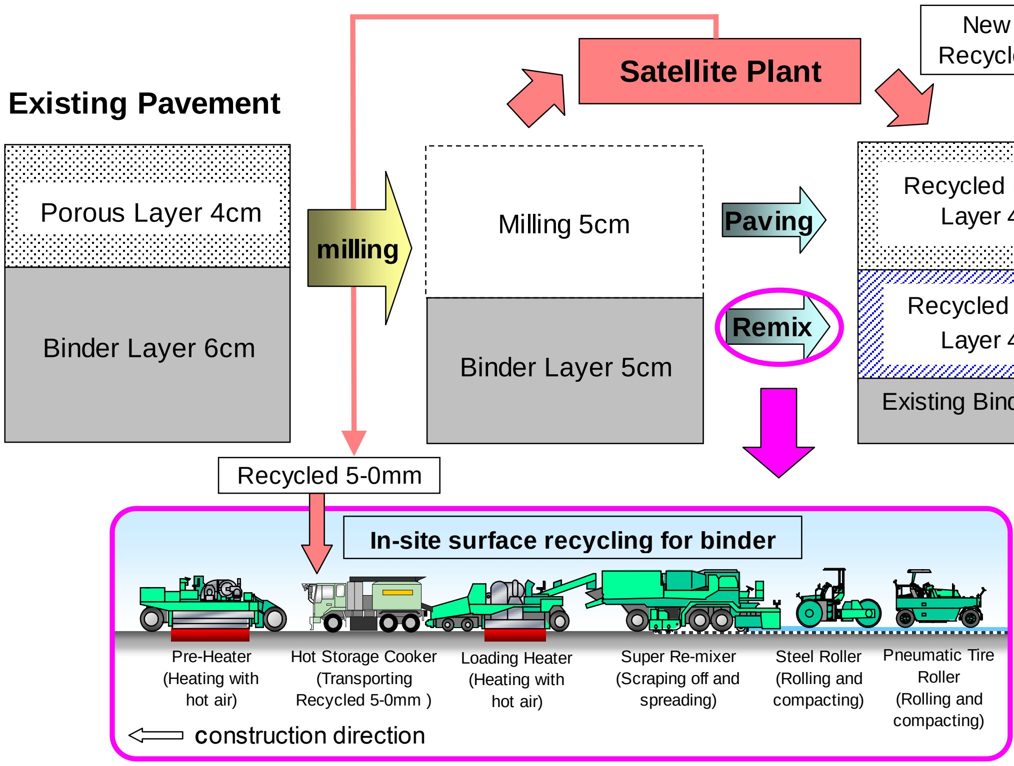

Figure 1: Concept of recycling system

First existing entire porous layer and part of binder layer in the field are milled and shipped to the satellite plant. The materials are then divided into two sizing: 13-5mm for recycled porous mix and 5-0mm for recycled binder mix to be added in the surface recycling. The former is going to be rejuvenated using special additives and mixed with some portion of new porous materials at the plant, and then back to the site for paving. The latter is also rejuvenated but not mixed with any new materials at the plant, and shipped to the in-site recycling.

Because a tentatively built satellite recycling plant can be exclusively used for a specific project, qualified materials control for any local condition is possible. This is a big merit of the satellite plant and never achievable in a normal recycling plant that has to deal together with many other projects.

In the development of this recycling system, the following targets were set for mix condition.

#1 Recycled binder mix must have impermeability and sufficient dynamic stability.

#2 Recycled porous mix must have sufficient raveling resistance with 17% air voids or higher.

Table 1 shows the target mix condition.

Table 1: Target mix condition

Mix Type	Basic Performance	Test Method	Criterion
Recycled Binder Mix	Impermeability	Pressurized Permeable Test	equal to New Materials
	Flow Resistance (60℃)	Wheel Tracking Test	1000 times/mm or higher
	Stripping Resistance	Immersion Wheel Tracking Test	5% or lower
Recycled Porous Asphalt Mix	Permeability	Constant Head Permeable Test	equal to New Materials
	Flow Resistance (60℃)	Wheel Tracking Test	3000 times/mm or higher
	Abrasion Resistance (-20℃)	Contabro Test	20% or lower
	Crack Resistance (-10℃)	Bending Test (Breaking Strain)	equal to New Materials

Laboratory tests were conducted using porous surface and binder materials actually milled from road surface being planned for rehabilitation. Both of basic recycled binder and porous mixes to match the target condition were obtained.

4 ACCELERATED PAVEMENT TEST

Basic recycled binder and porous mixes were subjected to Accelerated Pavement Tester that is owned by NEXCO ERI, as shown in Photo 3. This indoor full-scale APT can control seasonal and rainy conditions, as well as put truck loadings at actual traffic speed for inner and outer passes. Because of accelerated loading and environmental simulation, this APT named ALES excels in evaluation of short to midterm durability of pavements; for example rutting for 5 to 10 years in the field can be generated only in a week. However ALES is not good at simulation of long-term ageing. Therefore ageing performance should be evaluated in a trial construction as later described.

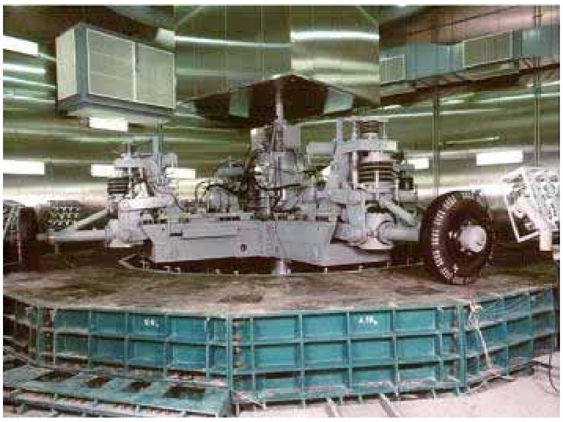

Photo 3: Accelerated Loading and Environmental Simulator (ALES)

Since both recycled porous surface and binder layers need to be sufficiently durable lest underlying binder layers should be weakened or rutted, the APT conditions were set as shown in Table 2.

Table 2: Full-scale APT condition

Outline of Test	Stripping Test	Rutting Test
Pass	Inner Pass	Outer Pass
Tire Type	Truck Dual	Truck Single
Wheel Load	5.0 ton	2.5 ton
Rotation Velocity	60 km/h	80 km/h
Pavement Temperature (2.5cm under Road Surface)	50℃	45-55℃
Wheel Shift	0mm	±100mm
Immersing Condition	Befor Run	None

In order to find the most durable mix, the combinations of APT specimen changing recycling ratio and in-site recycling depth for binder layer were set in Figure 2.

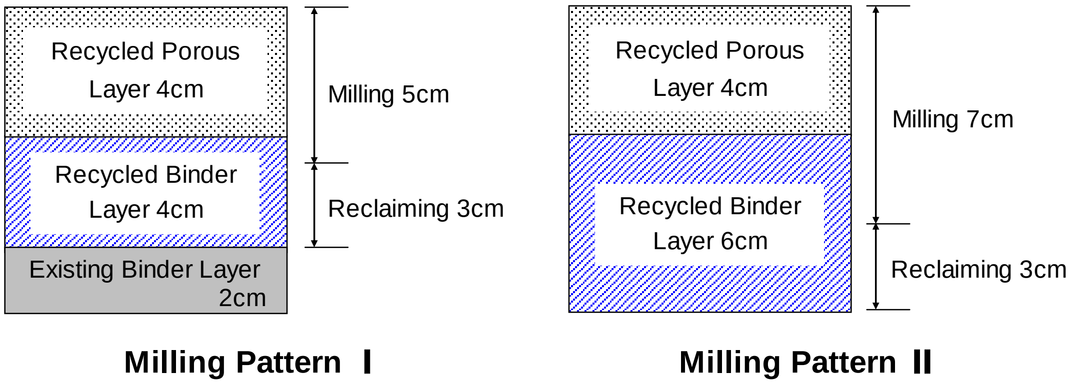

Figure 2: Combination of recycling ratio and in-site recycling depth

Figure 3 shows the result of binder layer's stripping test. The vertical stripping ratio was calculated from observing cross section of the block cores, which were sawed out from each specimen after the truck loadings of 4 × 900 thousand times. Unexpectedly all recycled mixes showed 0%, while new mix being 5.6%. This is speculated because the recycled binder mix has higher bitumen contents, that is composed of coated bitumen from the existing aggregates and polymer modified bitumen for rejuvenating. This superiority of recycled binder mix is also confirmed in Photo 4, showing cross section of each specimen.

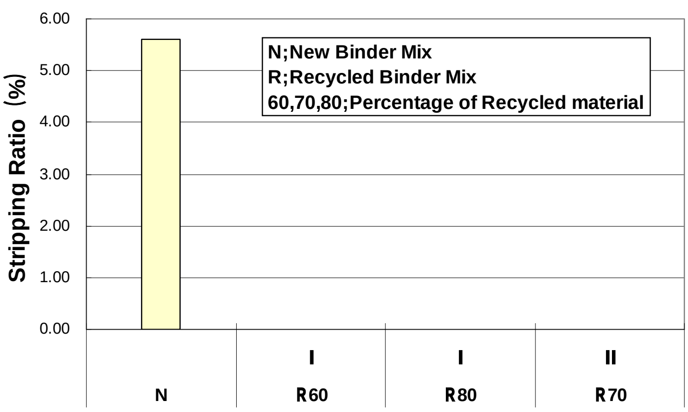

Figure 3: Stripping ratio of binder mix after Immersion Test (Inner Pass)

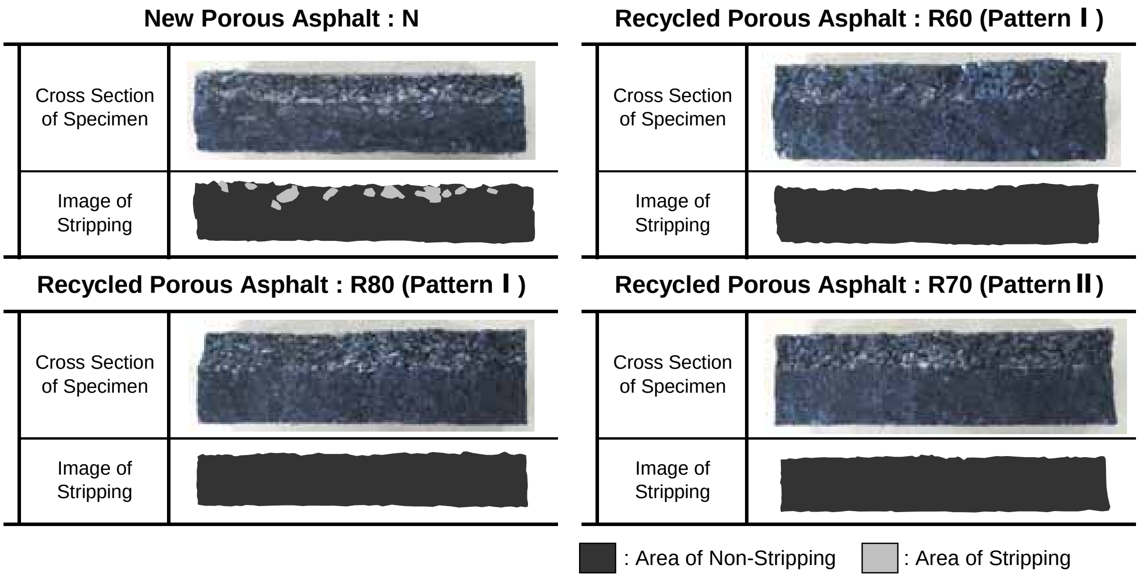

Photo 4: Cross section of binder mix after Immersion Test (Inner Pass)

Figure 4 shows the result of pressurized permeable test for binder layer. The test cores (φ10cm) were sampled from the same APT specimen, as above tested. 70% recycled mixes together with in-site recycling depth of 30mm showed lower permeability than new binder mix. Unexpectedly again, this indicates that the binder mix is going to be impermeable as with the increase of in-site recycling binder depth. This is considered also due to higher bitumen contents in proportion to the binder depth.

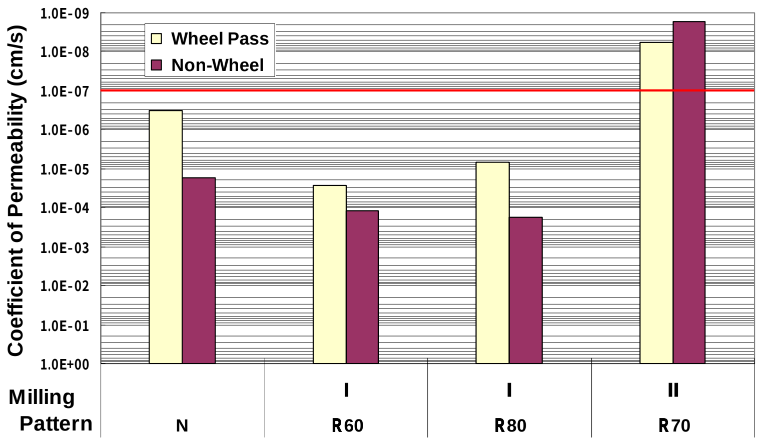

Figure 4: Pressurized Permeability of Binder Mix after Immersion Test (Inner Pass).

Figure 5 shows the result of rutting test until the truck loadings of 4 million times. All the recycled mixes showed sufficiently higher rutting resistance than new binder mix. This is speculated due to the lower penetration effect of recycled materials, as is usually observed in wheel tracking test.

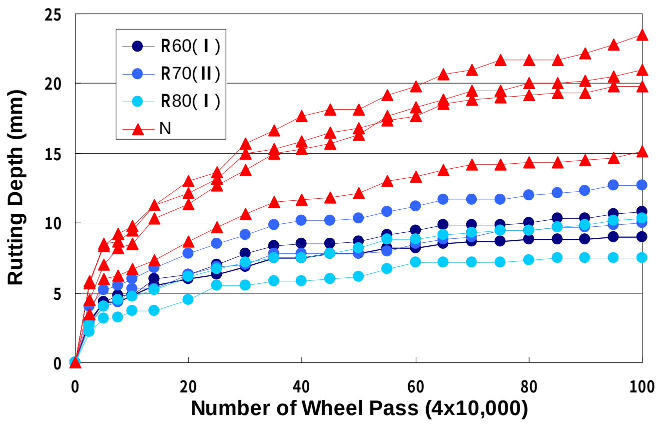

Figure 5: Rutting test result (Outer Pass)

From the above APT tests, durable combinations of recycling ratio and in-site recycling depth for binder layer were selected. Table 3 shows the selected mixes to be used for the following trial recycling in the field.

Table 3: Selected mixes for trial construction

Mix Type	Mix Design	
Recycled Binder Mix	Thickness of Recycled 5-0mm	10mm
	Thickness of Reclaim (Existing Binder Layer)	30mm
	Rejuvenator	4%(against Asphalt Content of Binder Layer)
Recycled Porous Asphalt Mix	Percentage of Recycled Material	70%*
	Percentage of New Material (13-5mm)	30%*
	Total Binder Content (Rejuvenating Additives included)	4.9%

* Percentage of Recycled Porous Asphalt Mix Only

5 TRIAL RECYCLING

Figure 6 shows locations of a trial recycling site and a satellite plant. The recycling site is a truck yard inside Kazo-Interchange. The satellite plant, which was actually used for this trial project was an existing recycle plant, locating just 2km from the interchange. This is for the purpose of carefully understanding the whole of recycling procedures both at plant and in the filed, before launching the costly investment of building up an actual satellite plant.

Figure 6: Location of trial recycling site and plant

Because of this objective 5cm thick materials, including 4cm porous and 1cm thick binder layers were milled in the site and shipped to the plant, several days before in-site recycling for the binder layer, followed by paving for the recycled porous layer. The shipped materials were divided into 13-5mm and 5-0mm sizing for the two layers. The rest of 77% of milled materials after disposal (23%) are going to be used. Then mix design was conducted for deciding how both layers to be recycled. Figure 7 shows a scheme of the trial project.

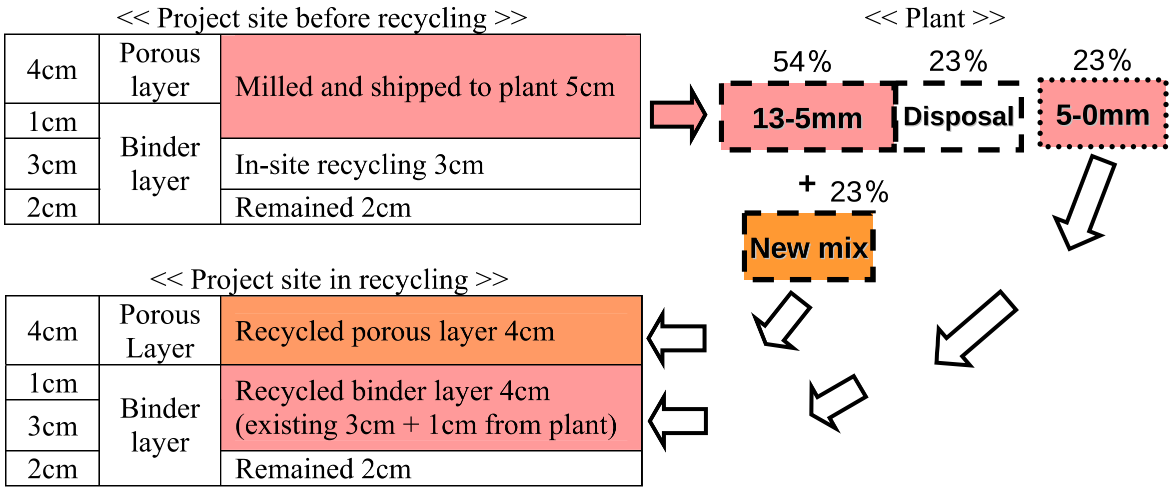

Figure 7: Scheme of trial project

Photo 5 shows in-site surface recycling for the binder layer. Existing 3cm thick binder layers were first heated and then reclaimed. The reclaimed materials were to be remixed using rejuvenating additives with 5-0mm recycled materials from the plant, and then the remixed materials were finished and compacted at a time. Finally recycled binder layer was properly constructed as designed.

Photo 5: In-site surface recycling for the binder layer

Table 4 shows mix properties of the binder layer at both times of mix design and recycling in the field. The materials obtained in the field showed almost the same properties as in the mix design.

Table 4: Mix properties of the binder layer

Item	Marshall Stability (kN)	Residual Stability (%)	Coefficient of Permeability (cm/s)	Dynamic Stability (times/mm)	Bending and Breaking Strain x10-3(cm/cm)
Trial Recycling	6.7	90	5.2x10-6	1120	3.8
Mix Design	7.1	86	4.7x10-6	1160	3.6
Targeted Value	6.0 or more	75 or more	equal to New Materials	1000 or more	-

After paving the binder layer was over, 13-5mm recycled materials composing of originally divided 13-5mm and some portions of new materials with rejuvenating additives. Photo 6 shows finishing the recycled materials for the porous layer. This layer was also successfully constructed as designed.

Photo 6: Finishing the recycled porous layer

Similarly as Table 4, Table 5 shows mix properties of the porous layer for mix design stage and recycling in the field. The porous materials in the field also showed almost the same as in the mix design.

Table 5: Mix properties of the porous layer

Item	Percentage of Air Void (%)	Marshall Stability (kN)	Residual Stability (%)	Low Temperature Contabro Wastage Ratio (%)	Dynamic Stability (times/mm)	Bending and Breaking Strain $x10^{-3}$(cm/cm)
Trial Recycling	20.5	5.1	86	13.1	5490	7.6
Mix Design	19.1	5.0	84	9.6	6300	9.1
Targeted Value	-	5.0 or more	75 or more	-	3000 or more	-

Photo 7 is a close look at recycled porous road surface finally obtained. This road surface showed sufficient levels in permeability and skid resistance as with new materials.

Photo 7: Recycled porous road surface

Finally it was proved that the whole recycling system, that is a combination of a satellite plant being tentatively built nearby the project site together with in-site surface recycling for binder layer, is technically possible as designed.

6 COCLUSION

For the purpose of fully recycling porous and binder layers materials, possibility of a satellite recycling plant and in-site surface recycling for binder layer was studied. The findings were summarized as follows.

1. According to Accelerated Pavement Test, all the recycled binder mixes showed superior durability in stripping ratio to new binder mixes. This is speculated because the recycled binder mix has higher bitumen contents, that is composed of coated bitumen from the existing aggregates and polymer modified bitumen for rejuvenating.
2. The test cores (φ10cm) sampled from the APT specimen showed the tendency that the binder mix is going to be impermeable as with the increase of in-site recycling binder depth. This is also considered due to higher bitumen contents in proportion to the depth.
3. All the recycled mixes showed sufficiently higher rutting resistance than new binder mix in the APT. This is speculated due to the lower penetration effect of recycled materials.
4. Because sufficient mix and road surface properties were obtained in a trial recycling project, it was finally judged that the whole recycling system is technically possible.

The combination of satellite plant recycling and in-site surface recycling for binder layer is to enable a direct porous to porous recycling as well as binder layer's improvement. In other words the two layer's innovative recycling method finally realizes reuse of 80% existing materials. For more consistency of this method trial constructions in the actual roadway and the follow-up surveys in the long term need to be conducted.

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