LONG LASTING DURABLE MIX AS ALTENATIVE OF POROUS ASPHALT

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ABSTRACT

A hybrid type of mix, which is composed of rough macro texture for road surface similar to that of porous asphalt, as well as the same waterproof as that of stone mastic asphalt (SMA) for inside was developed in NEXCO RI. For the two opposing functions in the concept, aggregate gradations of the hybrid mix were examined with a combination of porous gradation for stone part and SMA gradation for sand part. By subjecting many roller-compacted specimens to laboratory tests, a prototype hybrid mix was finally obtained under a very limited aggregate gradation range with specific mix properties. A full-scale durability test showed that even after a steel ploughing vehicle moving 200 times on the surface, the hybrid survived almost no damages while porous asphalt much damaged. In order to solve bitumen's run-off problems found in several projects, the prototype mix was reviewed for achieving less compaction energy by reducing compaction blow times from 75 to 50 times. Finally a newly obtained mix enabled easier construction with a sufficient texture and impermeability. This hybrid, one finishing mix with two functions is expected to provide with sufficient safety and long lasting durability as alternative of porous asphalt.

1. INTRODUCTION

Safety is one of the most important services that road operators should assure for road users. Under this concept nationwide three toll expressway companies, namely East, Central and West Nippon Expressway Company Limited (NEXCO) that is engaged in construction, operation and maintenance of their toll expressways in Japan, has been promoting the use of porous asphalt since 1989.

While ravelling has always been concerned in European countries [1], polymer modified bitumen with higher SBS contents for porous asphalt [2] [3] has been successfully used for longer durability that assures ravelling and clogging resistance. However in heavy snowfall areas like Hokkaido, where snow is to be removed using steel edges on the roadway, the pavement is severely abraded by the edges. Although stone mastic asphalt is a countermeasure against severe abrasion, NEXCO has a strong policy that road surface for their motorways must be of porosity. Figure 1 supports their safety policy by confirming a drastic reduction of rainy traffic accidents for a year before and after construction of porous asphalt [4], which was observed in their expressways. This is considered because sufficient macro texture on the porous road surface can be obtained for longer years than that on the dense grade, as shown in Figure 2.

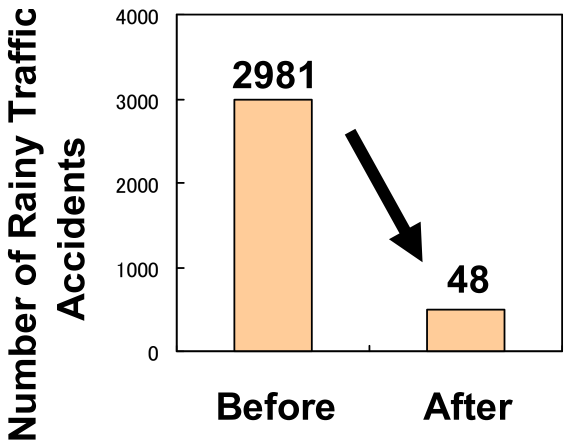

Figure 1 - Effect of porous asphalt [4]

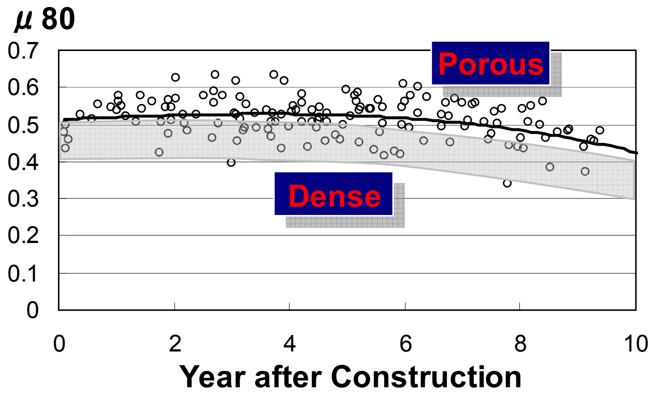

Figure 2 - Sustainable skid resistance

Because the pavement is needed especially in snowy and cold regions, where slippery accidents are more likely to take place, there have been sometimes serious scaling and abrasion as shown in Photo 1. Besides there have been unfamiliar underlying layer based problems in ordinary region. Photo 2 shows blowing up of particles of the underlying binder layer's mixture, which was weakened by remained water in an ordinary section.

Photo 1 - Scaling and abrasion

Photo 2 - Particles blowing up from Porosity

Because these distress types shorten the life of pavement and increase repair costs, longer lasting safe and durable alternative mix has come to be strongly needed. From this view the NEXCO Expressway Research Institute started the development of a new type of mix, called "Hybrid," namely to assure sufficient skid for surface and impermeability for inside, although these targets are quite contradictory [4].

This paper presents a complete development of hybrid mix until it is prescribed in NEXCO as alternative of porous asphalt mix.

2. CONCEPT OF HYBRID

Hybrid mix was designed to have rough macro texture for road surface similar to that of porous asphalt, as well as the same impermeability as that of stone mastic asphalt (SMA) for inside was developed. The target requirements of the mix are as follows.

- Surface texture as porous asphalt with 17% air void
- Impermeability as SMA
- Resistance against flow rutting, ravelling and stripping of aggregates as SMA
- One finishing mix to be paved in the field

In order to realize the above requirements, the concept is drawn in Figure 3.

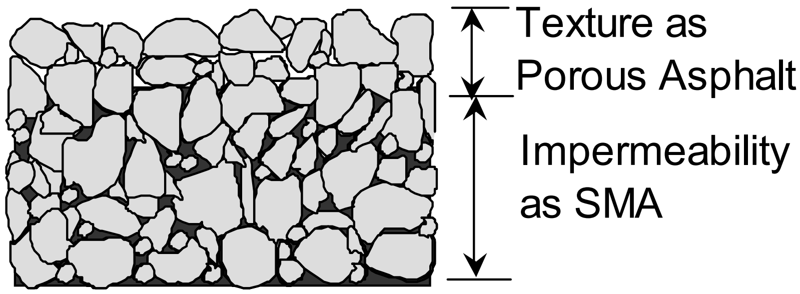

Figure 3 - Concept of Hybrid Mix [4]

For the two opposing rough texture and impermeability, aggregate gradations of the hybrid mix were examined with a combination of porous gradation for stone part and SMA gradation for sand part. This expects coarse aggregate to build up aggregate skeleton and mastic mortar to be filled in the air voids below. The target gradations are narrowed down, as shown in Figure 4. Lower SBS content modified bitumen than that being used for porous asphalt was selected for the development of hybrid mix for reducing cost [4].

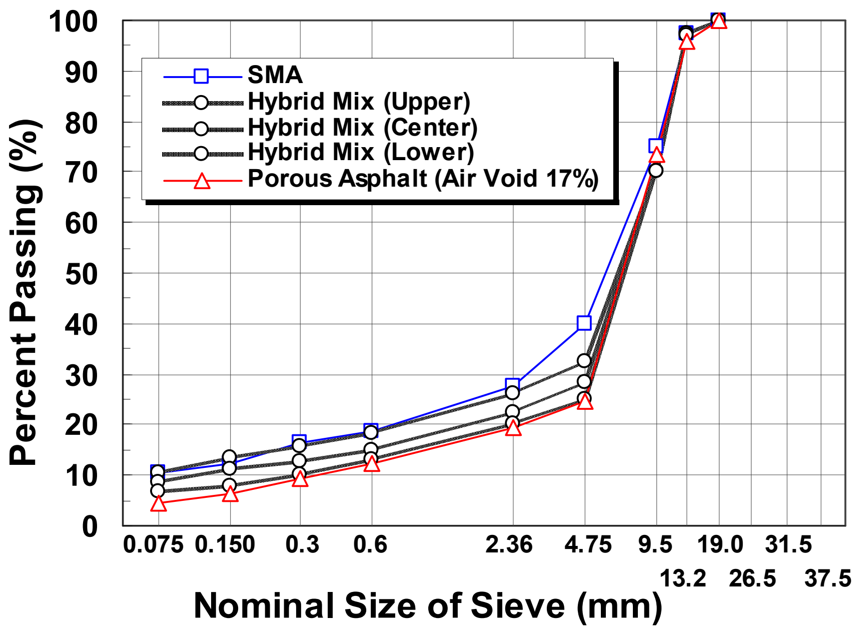

Figure 4 - Gradation curves for Hybrid Mix [4]

3. AIR VOID EVALUATION

For air void control, bulk specific gravity (BSG) is usually used for open graded mix and effective specific gravity (ESG) for absorptive dense mix. Because hybrid has the two aspects for a mix, both BSG and ESG are used for air void evaluation, as shown in Figure 5. Air void to be calculated from vacuum-packed BSG is used for evaluation of surface texture as porous asphalt, while that based on ESG is for impermeability as SMA [4].

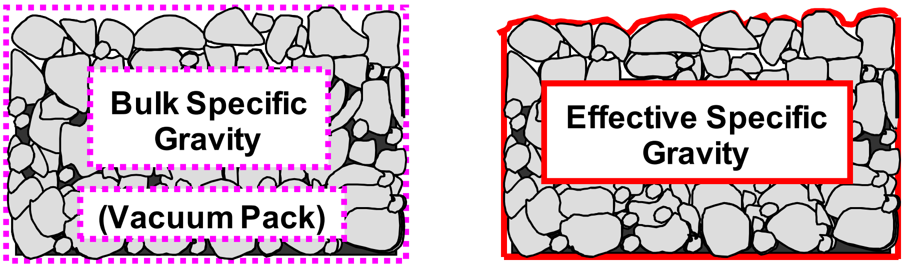

Figure 5 - Two types of gravities for Hybrid Mix [4]

4. TEXTURE & IMPERMEABILITY

Three hybrid gradations in Figure 6 were selected for the basic evaluation of rough texture and permeability. Marshall specimens with 75 compaction blows for a side were first used to determine optimum bitumen content. For evaluating texture and permeability of the mix, laboratory specimens were fabricated using a roller compactor that is expected to give similar compaction in the field. Figure 6 shows differences in texture by Mean Profile Depth (MPD) between hybrid mixes depending on percent passing 4.75mm sieve. Porous asphalt mix with air void 17% to be used in snowy and cold regions showed MPD 1.9mm. For hybrid mix MPD 1.2mm was set for a minimum level as average deducted by one standard deviation. In order to assure this MPD level, the percent passing is considered 30% or lower.

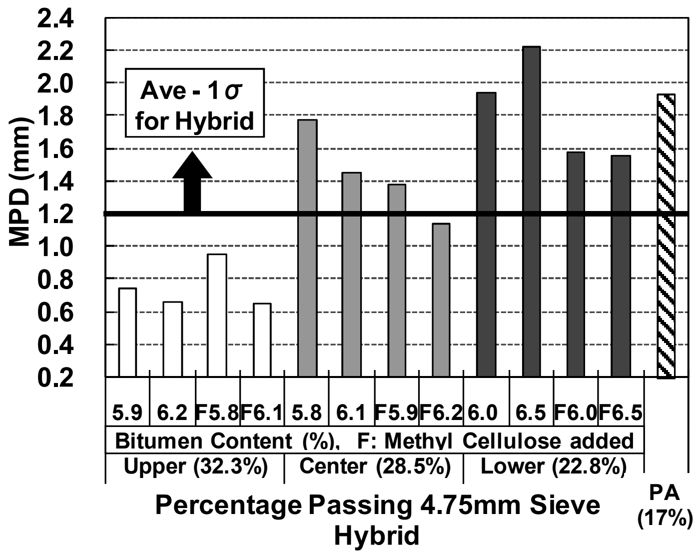

Figure 6 - Evaluation of rough texture [4]

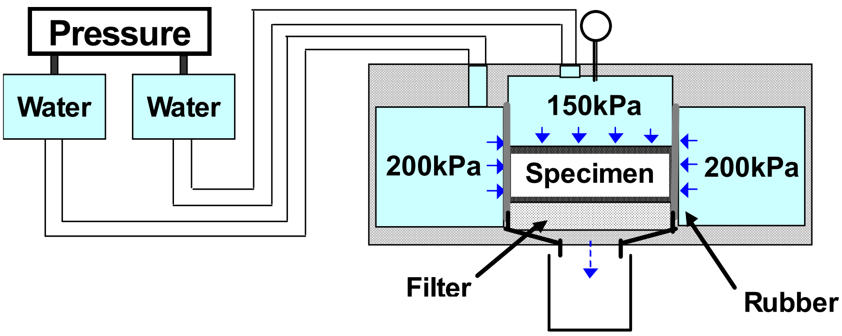

Figure 7 - Pressure Permeable Test [4]

As for permeability, specimens being cored from roller compacted specimens were subjected to pressure permeable test [5] in Figure 7. The permeability was calculated using volume of filtered water for 10 minutes after the cored specimen was put for 24 hours under pressure.

Permeability level of 1.0×10^{-7} in this test is regarded as impermeable since it is used in dam structure for waterproofing level in Japan. According to Figure 8, centre gradation with 5.8% bitumen content is assured for impermeability, thus pointing to maximum air void level of 2.8% in tendency based on ASG, which were obtained from Marshall specimens in Figure 9.

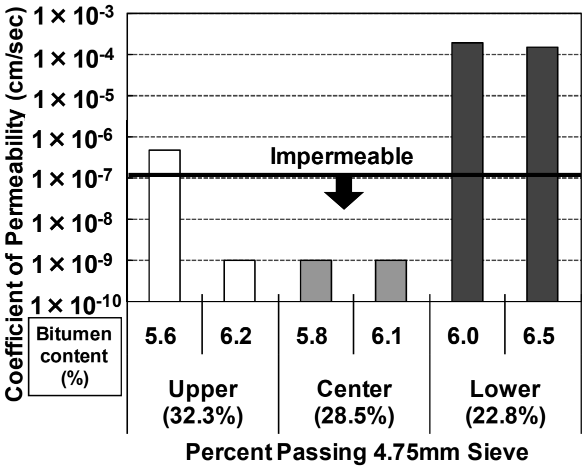

Figure 8 - Evaluation of permeability [4]

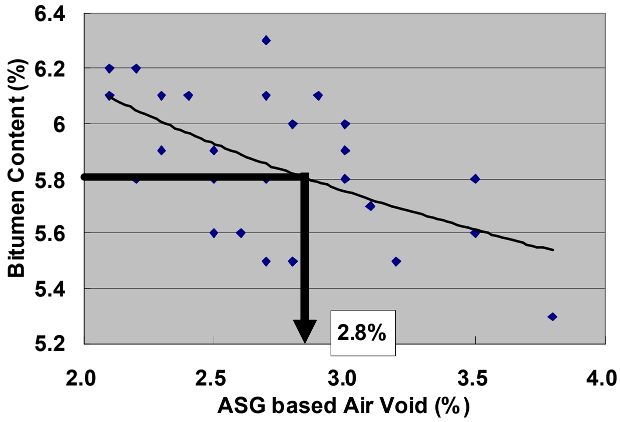

Figure 9 - Air void for impermeability [4]

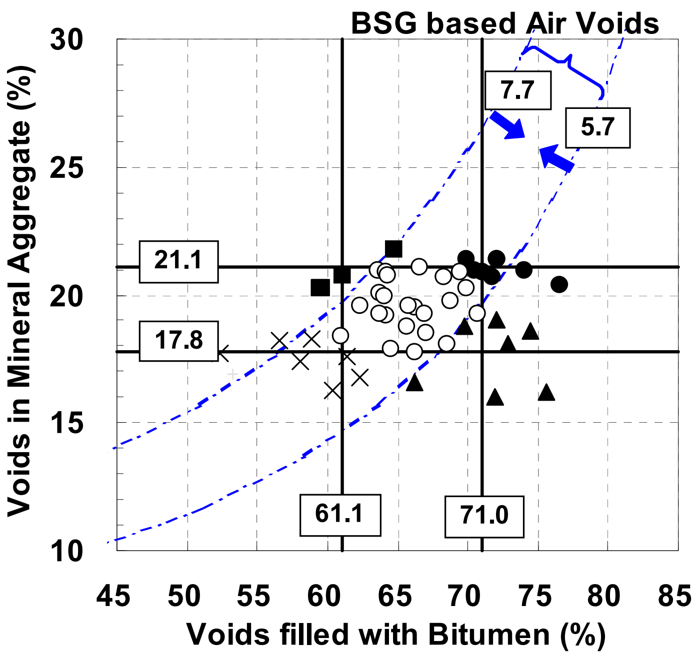

Figure 10 - Requirements for Marshall Mix [4]

After conducting wheel-tracking tests for resistance against flow rutting, the relationship between voids in mineral aggregate (VMA), voids filled with bitumen (VFB) and hybrid mix functions including texture, permeability and rutting resistance was summarized in Figure 10. VMA and VFB, which were obtained from Marshall specimens, are directly shown, while the functions from roller compacted specimens are shown by marks inside. Only white round mark shows all satisfaction with texture, impermeability and rutting resistance, and the other marks fail in either of the functions. Areas being surrounded by VMA, VFB and BSG based air voids meet all requirements for Marshall specimens to achieve basic hybrid properties; that is VMA between 17.8% and 21.1%, VFB between 61.1% and 71.0% and BSG based air voids between 5.7% and 7.7% [4].

5. PROTOTYPE MIX

Durability tests were conducted using the mixes that have survived in Figure 10. All the specimens in the following tests were fabricated using a roller compactor. Figure 10 summarizes rutting resistance and bending strain. Dynamic stability (DS) stands for rutting occurrence of 1mm in the specimen by wheel tracking passes at 60°C [6]. Bending test was conducted with loading rate of 50mm/min at -10°C. All the mixes exceeded DS level of 5000, showing sufficient rutting resistance under heavy traffic in Japan. They also exceeded bending strain of 6.0×10^{-3} being required for SMA.

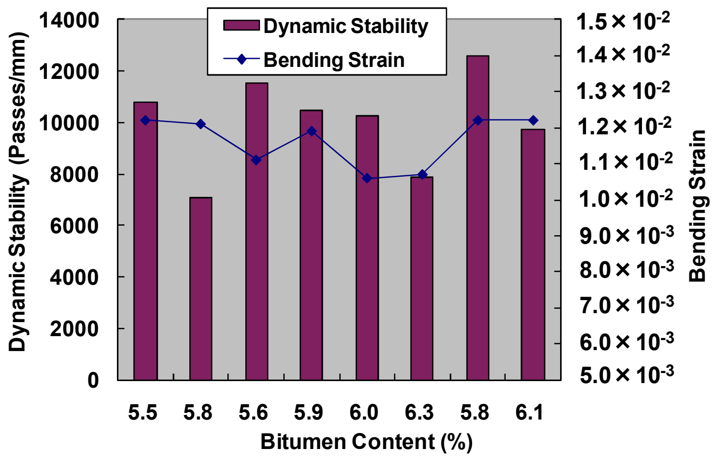

Figure 10 - Rutting resistance and bending strain [4]

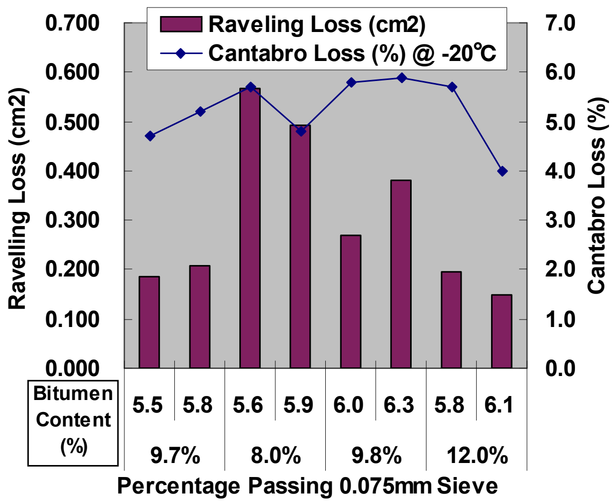

Figure 11- Abrasion and stripping of aggregate [4]

Figure 11 summarizes resistances against abrasion and stripping of aggregate. Abrasion test was conducted using cross chains repetition for 90 minutes at -10°C. As for stripping of aggregate Cantabro Test was conducted at -20°C. All the mixes survived less than 1.1 cm^2, showing sufficient resistance against tire chains for snowy areas in Japan. They also sufficiently survived less than 20% being required for porous asphalt mix in those areas.

Finally it was concluded that durable hybrid mix for motorways can be designed under a very limited aggregate gradation range with specific Marshall Properties, as shown in Table 1 as prototype mix [4].

Table 1 - Prototype gradation and Marshall Standard (75 Blows) [4]

Gradation Range			Marshall Properties		
Percent Passing of Sieve Size			**Vacuum Packed Bulk Specific Gravity**		
13.2mm	**(%)**	**95.0 to100**	**VMA**	**(%)**	**17.8 to 21.1**
4.75mm	**(%)**	**28.0 to 30.0**	**Satureted degree**	**(%)**	**61.1 to 71.0**
2.36mm	**(%)**	**22.0 to 25.0**	**Air voids**	**(%)**	**5.7 to 7.7**
0.6mm	**(%)**	**18.0 to 20.0**	**Apparent Specific Gravity**		
0.075	**(%)**	**8.0 to 10.0**	**Air voids**	**(%)**	**2.8% or Lower**

6. FIELD PERFORMANCE OF PROTOTYPE

Photo 3 shows a party of snow removal vehicles using steel edges on the roadway in Hokkaido under East NEXCO. Even after snow removal is over, all vehicles need to be equipped with tire chains. Due to such extraordinary severe conditions, Photo 4 shows severely abraded road surface in a winter.

Photo 3 - Snow removal vehicles

Photo 4 - Severely abraded road surface

Photo 5 - Steel ploughing abrasion test

Since hybrid mix was urgently needed, a full scale durability test was conducted there. Photo 5 shows full-scale abrasion test by a snow removal vehicle contacting a steel plough on the road surface before winter. This ploughing was repeated 200 times that is an annual average snow removal times in heavily snowy and cold sections in Hokkaido.

Figure 12 compares the surface layer’s thicknesses and texture before and after the test for porous asphalt and hybrid pavement. The hybrid well survived with its thickness and texture not much changed in error level, while the porous was damaged with reductions in thickness by 3.1mm and in texture by 0.2mm. This reduction of 3.1mm is almost the same annual abrasion in the field for the areas. In other words this test is considered to well simulate distress to take place in the field. Therefore it was judged that the prototype hybrid mix provide with sufficient safety and long lasting durability [4] [7].

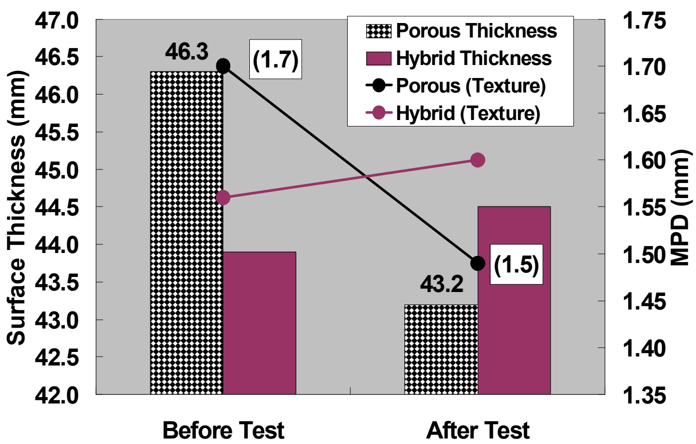

Figure 12 - Higher durability of Hybrid Pavement [8]

Figure 13 shows tyre/road noise level between three pavements in the field nearby Tokyo. Thanks to rough macro texture, noise mitigation of hybrid pavement is situated between those of porous asphalt and dense grade asphalt pavement.

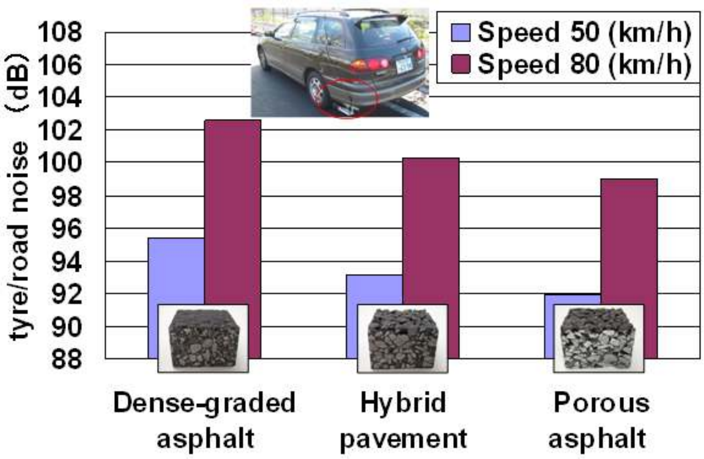

Figure 13 - Comparison of noise mitigation [8]

As shown in Photo 6, however, bitumen’s run-off problems during construction took place in several projects. This is considered because hybrid mix needs higher bitumen contents for its narrowed aggregate gradation. Thus it was judged that the prototype mix design procedure is to be reviewed for easier construction in the field [8].

Photo 6 - Bitumen's run-off problems [8]

7. REVIEW OF MIX DESIGN

Behind the difficulties during compaction of the materials in the field is that hybrid mix needs higher compaction energy in spite of its higher contents of coarse aggregates. Also bitumen's run-off problem is considered due to higher bitumen contents for achieving impermeability in mix design.

7.1. Performance Target

In order to realize less compaction energy in the field, reduction of compaction blows in the mix design that is 75 to 50 times is first to be considered. However this change means a new development of mix criteria, since only a change of compaction blows will make air voids higher, thus needing further bitumen contents and finally leading more of bitumen's run-off together with less macro texture in the field. Therefore while keeping the original target levels of texture, impermeability and durability sustained as shown in Table 2, new mix criteria for 50 times compaction blows was needed for development. [8]

Table 2 - Performance target for hybrid mix [8]

Item	Target
Mean Profile Depth（MPD）	**1.2 (mm), or higher**
Dynamic stability	**3,000 (times/mm), or higher**
Coefficient of permeability	**1×10^{-7} (cm/sec), or lower**
Cantabro loss (-20℃)	**12 (%), or lower**

7.2. Basic Marshall Properties

Figure 14 shows a relationship between voids in mineral aggregate (VMA) and voids filled with bitumen (VFB) for 50 times Marshall compaction blows. As with the increase of bitumen mortar, VMA tends to decrease. Also VFB together with VMA tends to increase as with the increase of bitumen contents in the mortar.

Based on this relationship, specific mixes that can assure the same levels of VMA and VFB respectively between 75 and 50 compaction blows are to be identified for use in the following laboratory tests [8].

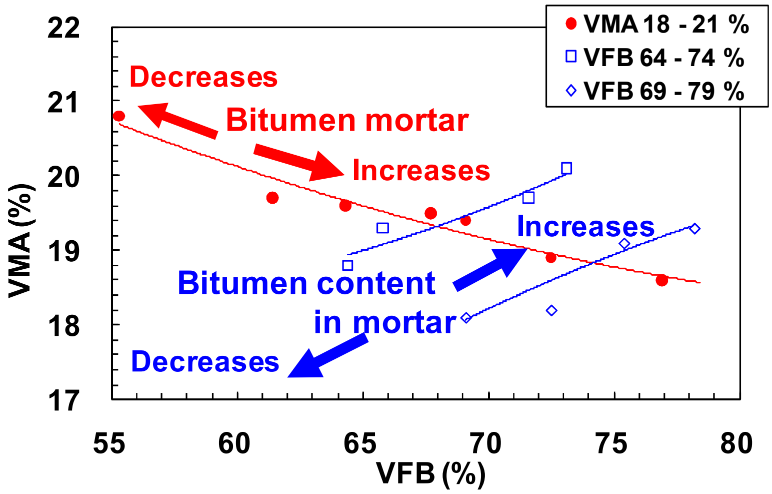

Figure 14 - VMA and VFB in changing bitumen mortar and bitumen content (50 blows) [8]

7.3. Laboratory Tests

Figure 15 shows a relationship between VMA and mean profile depth (MPD) as surface texture together with Cantabro loss at -20°C. Criteria of MPD and Cantabro loss are also put here from Table 2. Both MPD and Cantabro loss clearly tend to increase as VMA does. It was considered that VMA be less than 21% for satisfying Cantabro loss.

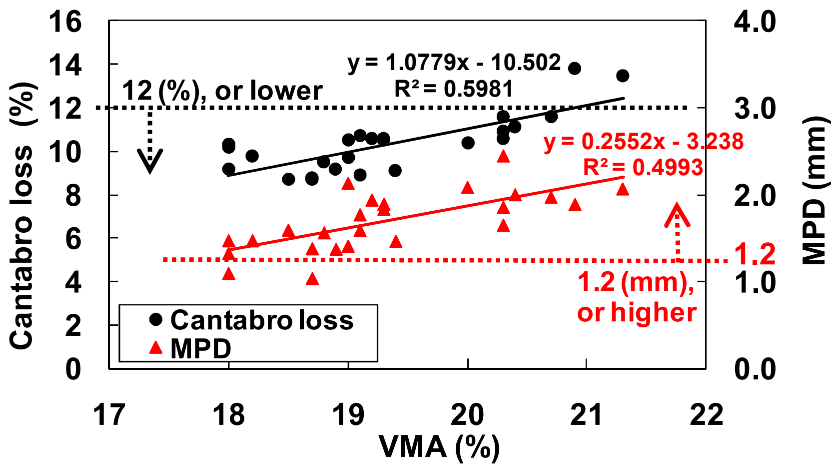

Figure 15 - MPD, VMA and Cantabro loss [8]

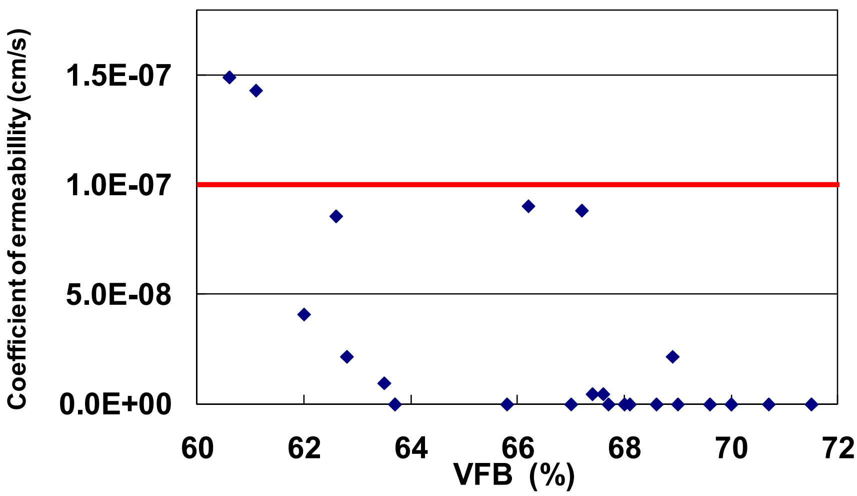

Figure 16 - VFB and permeability [8]

Figure 16 shows a relationship between VFB and permeability. Specimen for permeability test was obtained from roller-compacted specimen, as simulated in the field. VFB needs 62% or higher for achieving impermeability.

Dynamic stability for rutting resistance was obtained regardless of VMA and VFB, thanks to the use of polymer modified bitumen for the mix.
Figure 17 summarizes the relationship between VMA and VFB that satisfy all the performance requirements as targeted in Table 2. White round mark means all the satisfactory cases, while “×” mark does those including failure even in a requirement. All satisfactory cases surrounded by a blue line are obtained as tentative criteria in Table 3 [8].

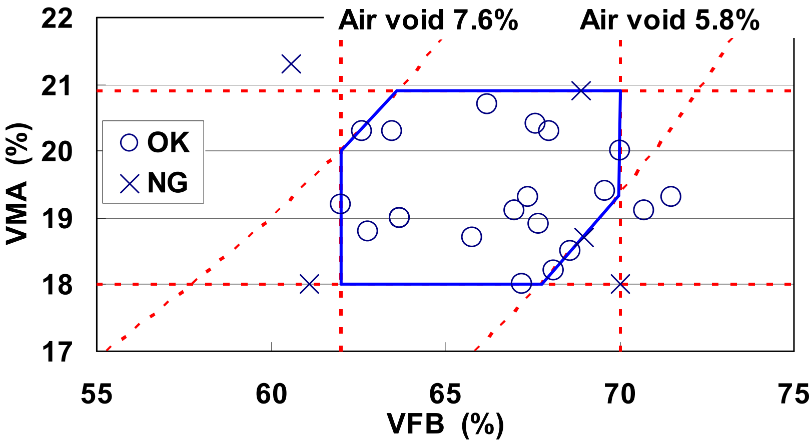

Figure 17 - VMA and VFB (50 blows) [8]

Table 3 - Tentative Marshall mix criteria (50 blows) [8]

Item	Higher limit	Lower limit
Air void (%)	7.6	5.8
VFB (%)	70	62
VMA (%)	21	18

7.4. Easier Compaction

In order to evaluate the improvement of compaction using new mixes, Figure 18 compares the levels of air voids and Gyration times between 75 and 50 blows mixes. Every two mixes with 75 and 50 blows here have the same levels of VMA and VFB. It was obviously revealed that 50 blows mix can be compacted less rotation times. Easier compaction will be naturally expected in the field [9].

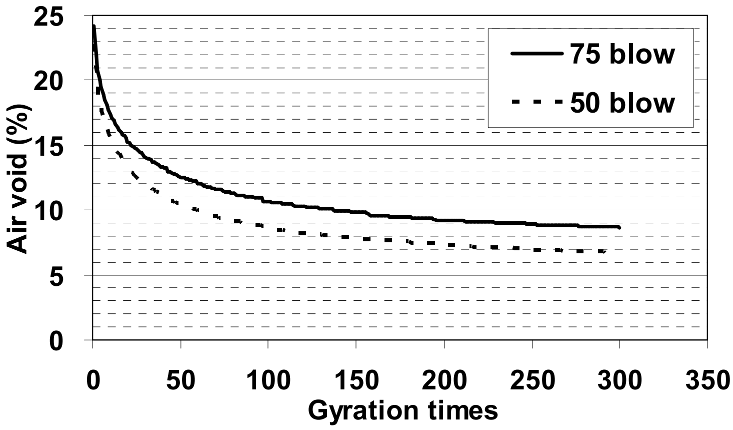

Figure 18 - Comparison of compaction blows [8]

8. ACCELERATED PAVEMENT TEST

In order to validate durability and performance of newly proposed hybrid mixes, a full-scale chain ravelling test was conducted using Accelerated Lading and Environmental Simulator owned by NEXCO RI in Photo 7. Figure 19 shows the improvement of ravelling resistance using a new mix. This is considered thanks to more of bitumen mortar in the new mix than that in the prototype.

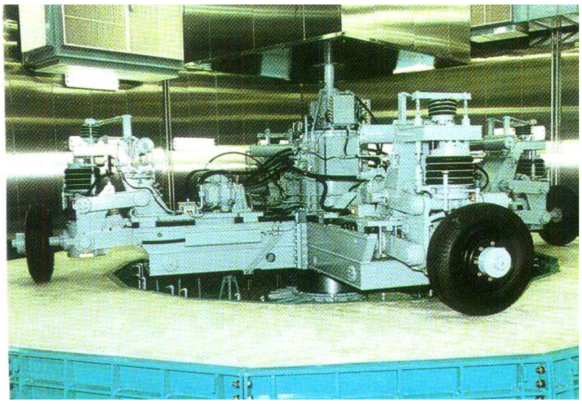

Photo 7 - Accelerated Loading & Environmental Simulator

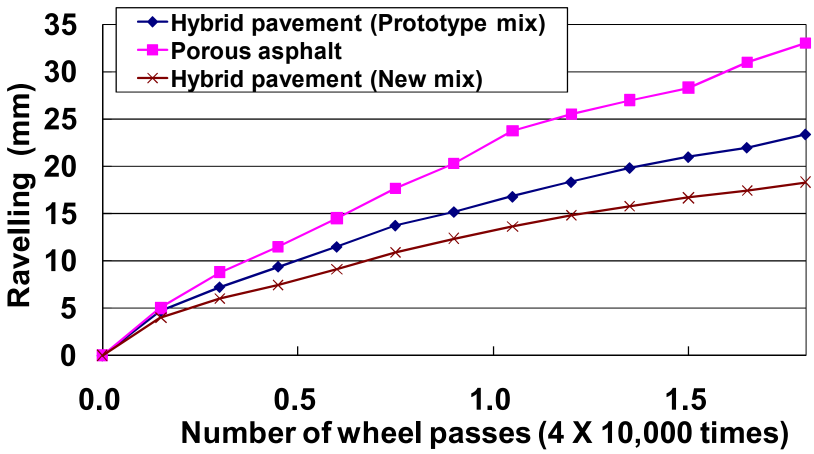

Figure 19 - Improved ravelling resistance [8]

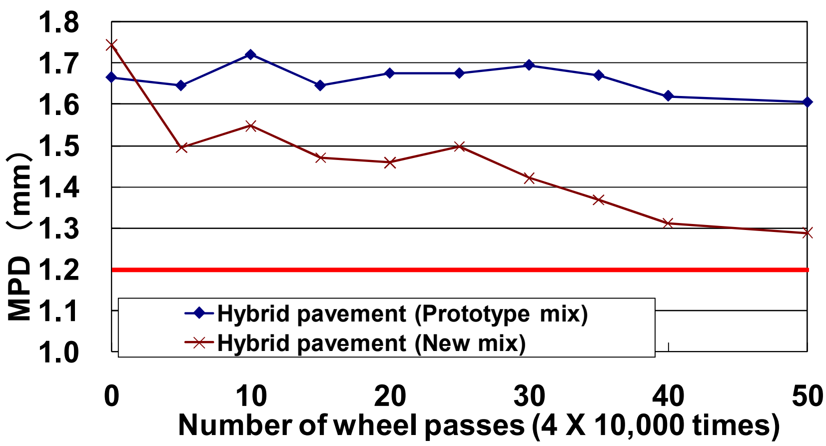

Figure 20 - Change in MPD (road surface: 40-55°C) [8]

On the other hand Figure 20 compares changes in MPD under hot temperatures. MPD of the new mix obviously decreases as test tires pass by. This is adversely affected by the increase of bitumen mortar in the new mix. Although there will never be such successively heavy truck loadings under hot temperatures in the field, the new mix is rather susceptible to lose MPD to hot temperatures than the prototype [8].

9. VALIDATION OF MIX CRITERIA

For the purpose of validating the new mix criteria of hybrid that can achieve easier construction in the field, 13 trial projects were conducted in the motorways under NEXCO. Each project referred to the gradations being used in Figure 17 and mix criteria in Table 3.

Photo 8 compares road surface just after construction, respectively using the prototype and new hybrid mix criteria in one of the projects. There are some bleeding spots in the former, while there is no difficulty at all in the latter. Table 4 supports the superiority of the new mix criteria, since it gives generally higher degree of compaction. The other projects also confirmed easier construction using the new criteria with no bleedings, and finally obtained performance target in Table 3.

Photo 8 - Comparison of road surface [8]

Table 4: Degree of Compaction [8]

Item		Area (A)	Area (B)
Prototype mix	Asphalt paver 1	96.8	96.6
	Asphalt paver 2	96.7	97.2
New mix	Asphalt paver 1	97.1	97.7
	Asphalt paver 2	99.0	97.6

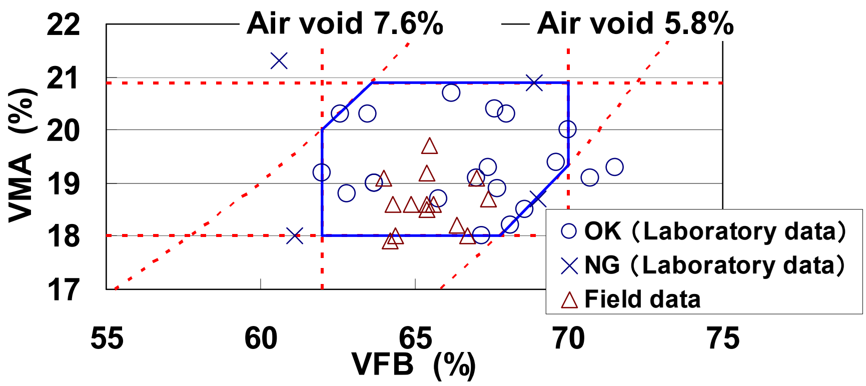

Figure 21 - VMA and VFB (all data) [8]

Figure 21 combined mix design data from the 13 projects to the previous laboratory data that was obtained in Figure 17. The vertical range for VFB matches field data, while there are three field data (Δ) lower than the horizontal blue line around at 18% for VMA.

Figure 22 shows a correlation of VMA and bitumen content in volume, which covers laboratory and field data. It was confirmed that the previous three points lower than VMA 18% are in line with the correlation. Moreover it was confirmed that the three points showed sufficient performance target in the field.

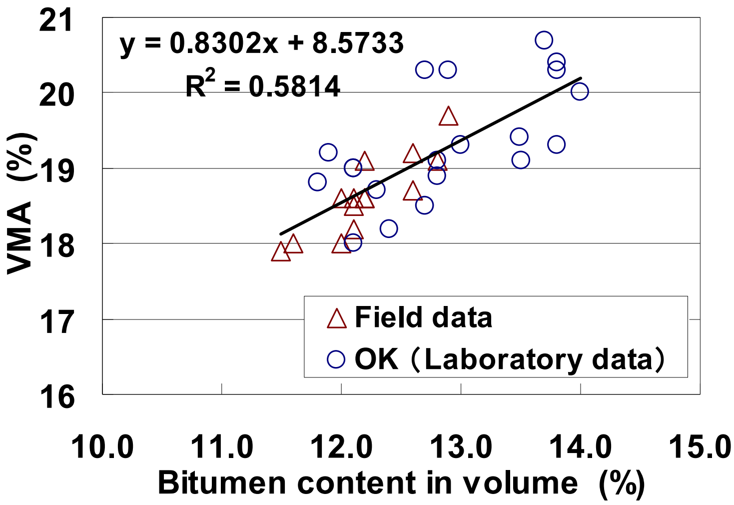

Figure 22 - VMA and bitumen content in volume (all data) [8]

As long as MPD is not sacrificed, a slight reduction of VMA well works for impermeability and improvement of durability, as well as decreases VFB, and thus in other words results in avoiding bitumen's run-off problems. Finally VMA levels around 18% were judged to be acceptable [8].

10. CONCLUSIONS

In order to assure long lasting safety and durability in the field, hybrid mix with rough macro texture as porous asphalt and impermeability as SMA was developed. The findings are summarized as follows.

1. Hybrid mix can be designed under a very limited aggregate gradation range with specific Marshall properties.
2. According to a full scale steel ploughing test, hybrid mix is expected to provide with sufficient safety and long lasting durability.
3. Noise mitigation of hybrid pavement in the field is situated between those of porous asphalt and dense grade asphalt pavement.
4. It was found that reduction of compaction blows from 75 to 50 times in mix design can effectively avoid bitumen's run-off problems during construction.
5. The relationship between VMA and mean profile depth (MPD) as surface texture together with Cantabro loss at -20°C revealed that both MPD and Cantabro loss clearly tend to increase as with VMA. It was considered that VMA be less than 21% for satisfying Cantabro loss.
6. Judging from the relationship between VFB and permeability, VFB needs 62% or higher for achieving impermeability.

7. Comparison of gyratory rotation times between 75 and 50 blows mixes that have the same levels of VMA and VFB, revealed that 50 blows mix can be compacted less rotation times. This will be truly expected in the field.
8. According to a full-scale chain ravelling APT test, 50 blows new mix is superior to the prototype. On the other hand, the new mix is rather susceptible to losing MPD under hot temperatures, although there will never be in the field.
9. In a trial construction comparing the prototype and new hybrid mixes, there are some bleeding spots in the former, while there is no difficulty at all in the latter. The new mix can give higher degree of compaction.
10. The relationship between VMA and VFB obtained in laboratory data almost matched mix design data from 13 projects. This was also confirmed in the relationship between VMA and bitumen content in volume.

The finally developed hybrid mix has been already implemented in the nationwide toll motorways under NEXCO since 2008. The authors strongly believe that this mix can be a good alternative of porous asphalt mix because it can assure long lasting safety and durability in the field.

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