Upgraded Mix Design Procedure of Hybrid Mix for less Compaction Energy

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ABSTRACT: Raveling of porous asphalt has always been a big concern in many countries (DRI-DWW, 2006). As a long lasting alternative, hybrid mix, which is composed of rough macro texture like porous asphalt, as well as the same waterproof as that of stone mastic asphalt (SMA), was successfully developed. As already reported in Zurich ISAP symposium 2008, hybrid pavement survived almost no damages with sufficient macro texture, even after loading a steel-edged snow plowing vehicle 200 times on the dry surface. Because of its texture, hybrid pavement in a Japanese motorway showed middle level in noise reduction between dense and porous asphalts. However bitumen's run-off during construction took place in several projects, since hybrid mix needs higher bitumen contents for aggregate gradation. Thus it was judged that the mix design procedure is to be reviewed for easier construction. While keeping target levels of texture, impermeability and durability sustained, in order to be able to reduce compaction energy in the field, laboratory compaction blow was changed from 75 to 50 times. Possible mix condition for 50 blows was finally obtained after doing considerable laboratory tests to understand the relation between voids in mineral aggregate and those filled with bitumen that satisfies the target levels. It was also found that gyratory rotations for 50 blows mix are smaller than those for 75 blows for a design air void. Finally it was judged from Accelerated Pavement Testing and field projects that this new mix procedure enables easier construction with a sufficient texture and impermeability.

KEY WORDS: Porous asphalt, stone mastic asphalt, mix design, criteria, compaction

1 INTRODUCTION

As a highly durable alternative of porous asphalt mix, hybrid mix that 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) has been implemented in the Japanese motorways under the control of Nippon Expressway Company Limited (NEXCO). Figure 1 shows the concept of the mix that is composed of coarse aggregate to build up a skeleton and mastic mortar to be filled in the air voids below. Therefore the hybrid mix can be paved as one finishing material (Kamiya et al. 2008).

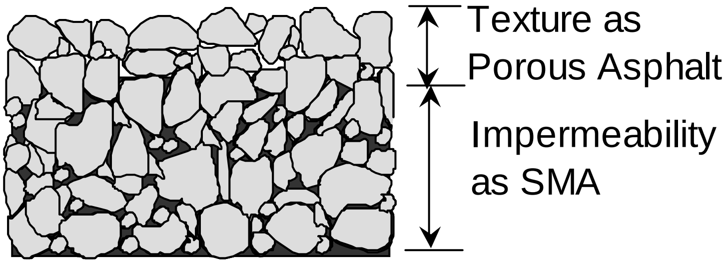

Figure1: Concept of hybrid mix (Kamiya et al. 2008)

According to a full-scale chain raveling test using Accelerated Loading and Environmental Simulator (Photo 1), it was confirmed that hybrid pavement has much higher raveling resistance than porous asphalt in Figure 2, as expected in the concept (Kamiya et al. 2008). Also thanks to its rough macro texture, it was observed in the field that the hybrid has sufficient skid resistance as well as noise reduction levels, as shown in Figure 3. Hybrid pavement is considered to have middle level in noise reduction between dense and porous asphalt pavements.

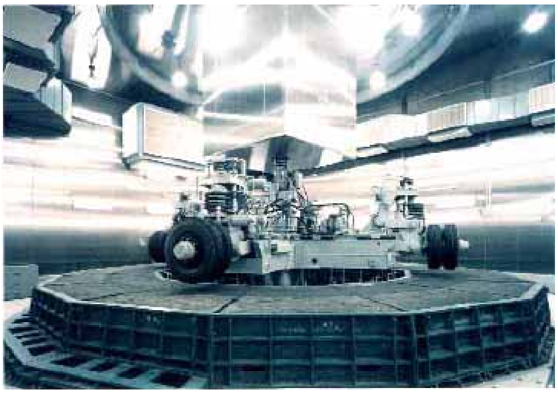

Photo 1: Accelerated Loading and Environmental Simulator (ALES)

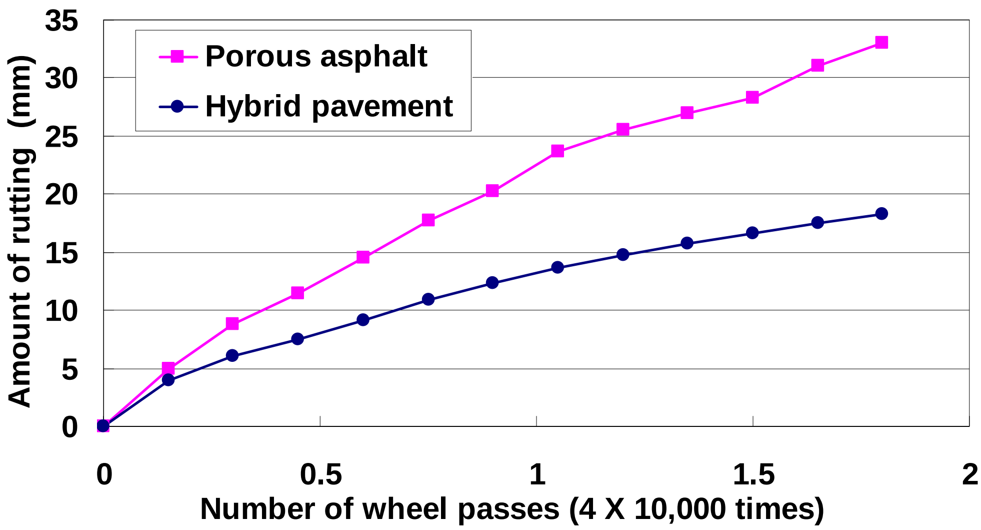

Figure 2: Comparison of raveling resistance

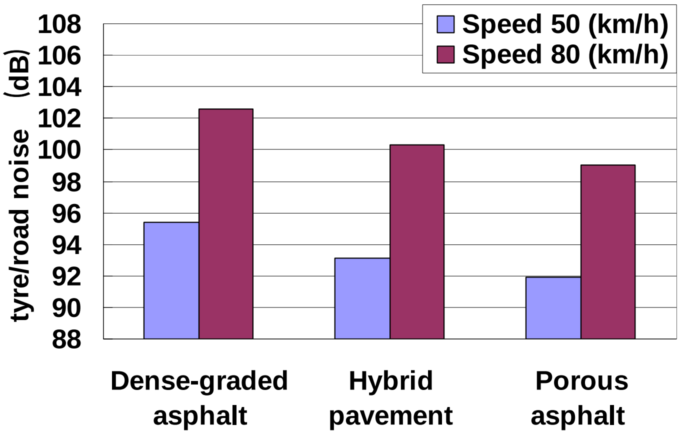

Figure 3: Noise reduction levels

As shown in Photo 2, however, bitumen's run-off problems during construction took place in several projects, since hybrid mix needs higher bitumen contents for its narrowed aggregate gradation ranges. Thus it was judged that the mix design procedure is to be reviewed for easier construction in the field.

Photo 2: Bitumen's run-off problems

2 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.

2.1 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 1, development of new mix criteria for 50 times compaction blows will be mentioned as follows. 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.

Table 1: Performance target for hybrid mix

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

2.2 Basic Marshall Properties

Figure 4 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. It must be noted here that bulk specific gravity is used for evaluation of air voids for surface texture while apparent specific gravity for impermeability in Figure 5 (Kamiya et al. 2008).

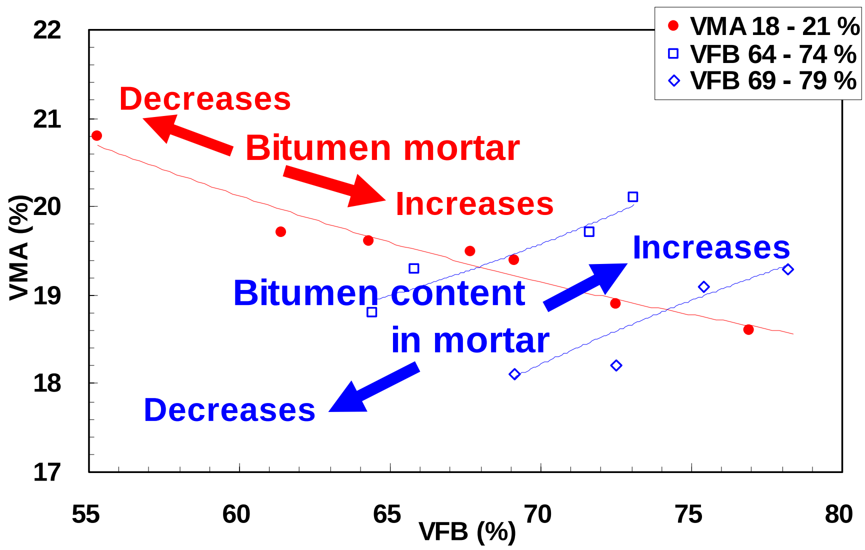

Figure 4: VMA and VFB in changing bitumen mortar and its bitumen content (50 blow)

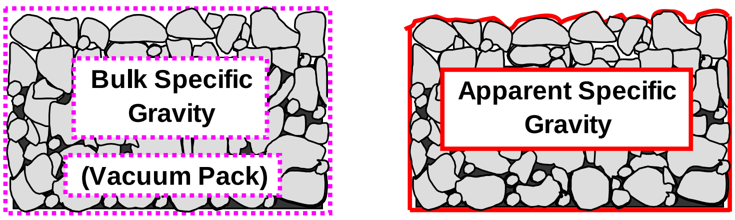

Figure 5: Two types of Gravities for Hybrid Mix (Kamiya et al. 2008)

2.3 Laboratory Tests

Figure 6 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 1. Both MPD and Cantabro loss clearly tend to increase as VMA does. It was considered that VFB be less than 21% for satisfying Cantabro loss.

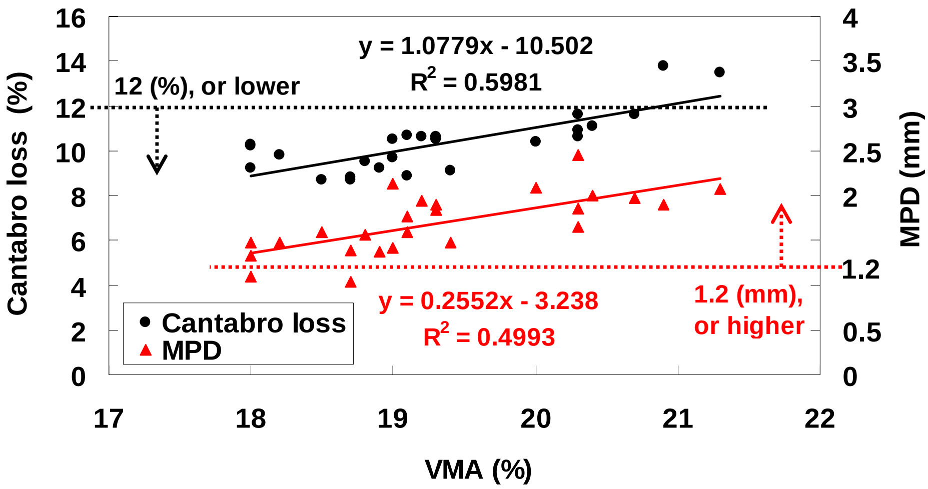

Figure 6: MPD, VMA and Cantabro loss

Figure 7 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.

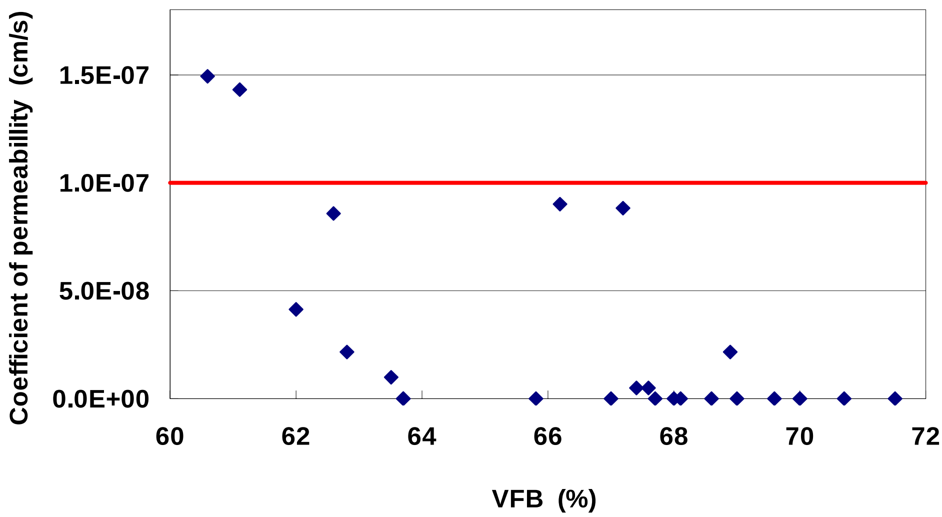

Figure 7: VFB and permeability

Dynamic stability for rutting resistance was obtained regardless of VMA and VFB, thanks to the use of polymer modified bitumen for the mix.

Figure 8 summarizes the relationship between VMA and VFB that satisfy all the performance requirements as targeted in Table 1. White round mark means all the satisfactory cases, while "×" mark does those including even a failure case. All satisfactory cases surrounded by a blue line are obtained as tentative criteria in Table 2, also together with tentative gradation range in Table 3.

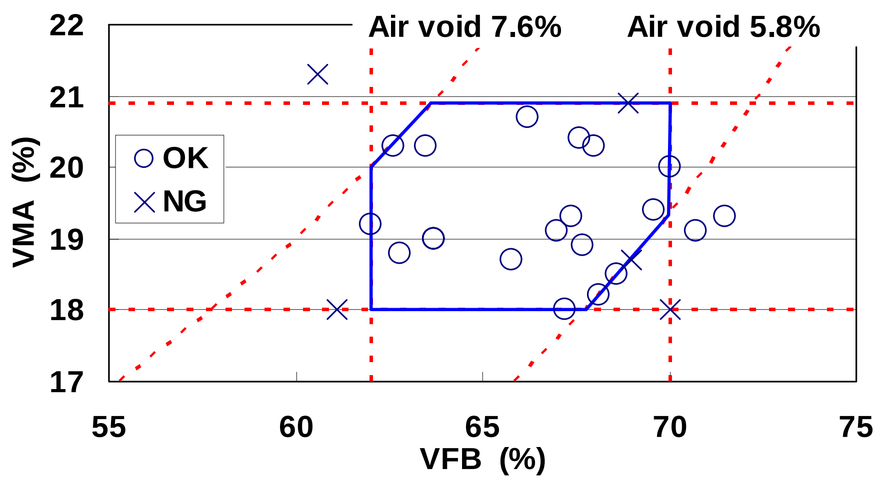

Figure 8: VMA and VFB

Table 2: Tentative Marshall mix criteria

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

Table 3: Tentative gradation range

Nominal size of sieve	Percentage passing No. n sieve (%)	
	Higher limit	Lower limit
19	100	100
13.2	100	95
4.75	38	30
2.36	27	22
0.6	21	17
0.3	18	15
0.15	13	10
0.075	11	9

2.4 Easier Compaction

In order to evaluate the improvement of compaction using new mixes, Figure 9 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. This will be truly expected in the field.

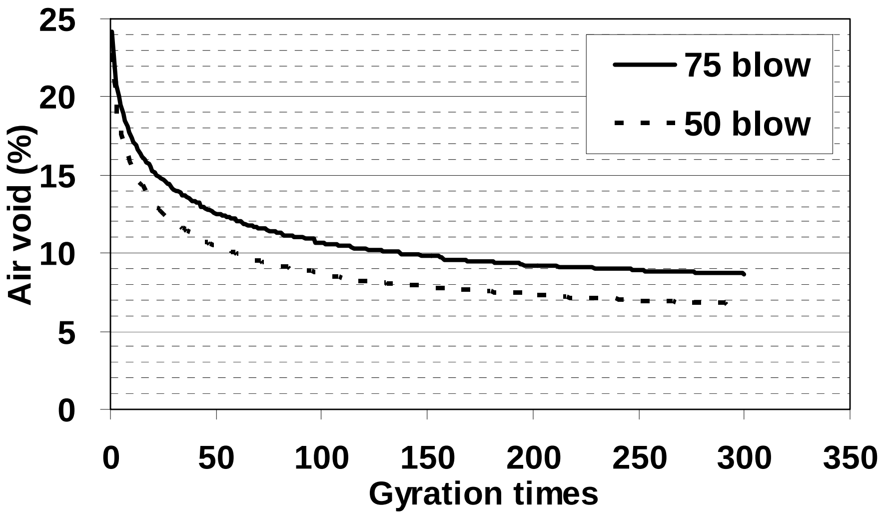

Figure 9: Comparison of compaction

3 ACCELERATED PAVEMENT TEST

In order to validate durability and performance of newly proposed hybrid mixes, a full-scale chain raveling test using ALES in Photo 1 was conducted. Figure 10 shows the improvement of raveling resistance using a new mix. This is considered thanks to more of bitumen mortar in the new mix than that in the conventional.

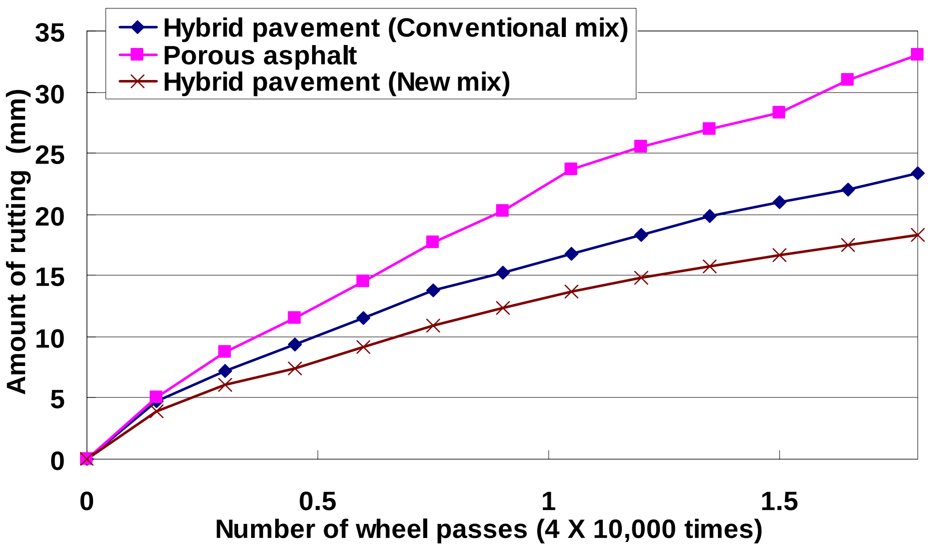

Figure 10: Improved raveling resistance

On the other hand Figure 11 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.

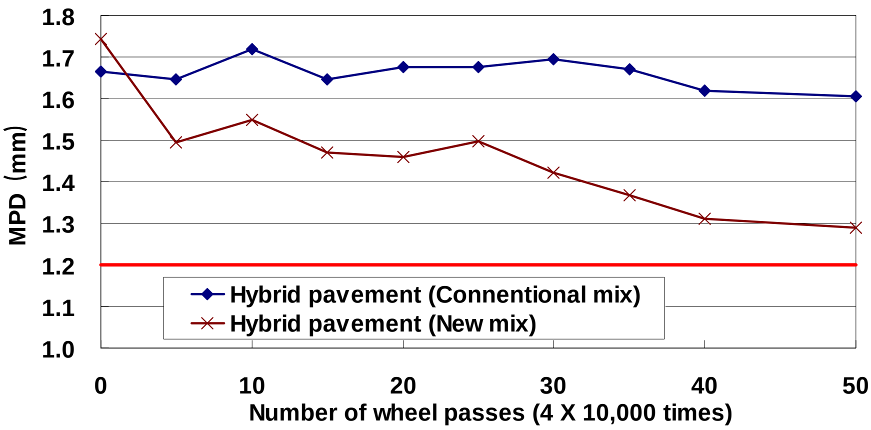

Figure 11: Change in MPD (road surface: 40-55°C)

4 TRIAL CONSTRUCTION

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 used for reference the tentative gradation range in Table 3 and mix criteria in Table 2.

In a certain project, Photo 3 compares road surface just after construction, respectively using the conventional and new hybrid mix criteria. 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 2.

Photo 3: Comparison of road surface

Table 4: Degree of Compaction

Item		Area (A)	Area (B)
Conventional 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 12 combined mix design data from the 13 projects to the previous laboratory data that was obtained in Figure 8. The vertical blue range for VFB well matches field data, while there are three field data (Δ) than the horizontal blue line at 18% for VMA.

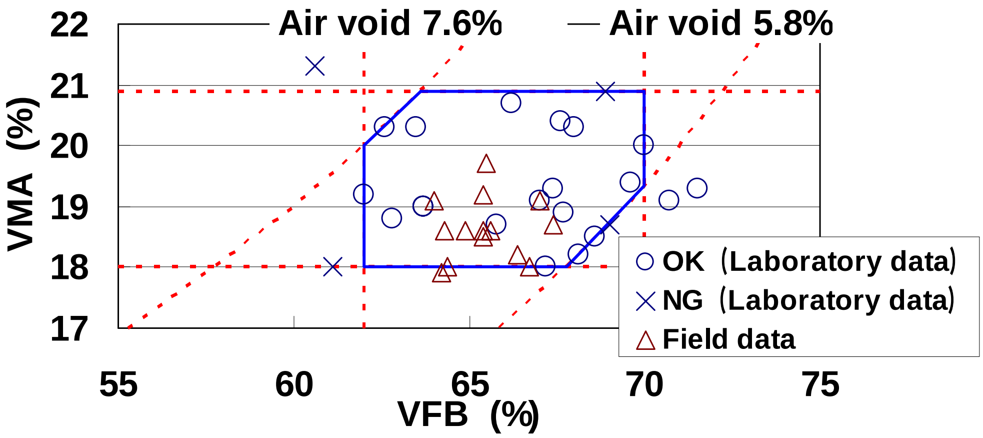

Figure 12: VMA and VFB (all data)

Figure 13 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.

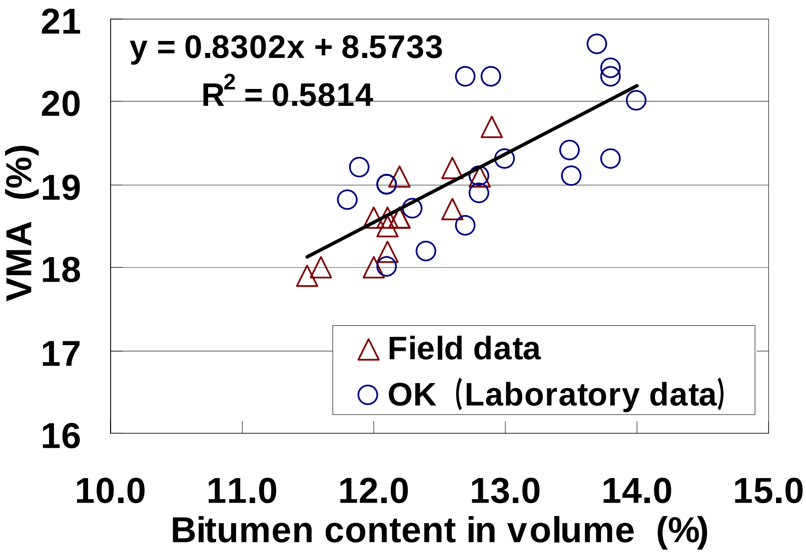

Figure 13: VMA and bitumen content in volume (all data)

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. Therefore it was judged that VMA levels around 18% will be acceptable.

5 CONCLUSION

For the purpose of realizing less compaction energy for hybrid mix in the field, new mix design criteria based on 50 times Marshall compaction blows was successfully developed in this study. The findings are summarized as follows.

1. According to the relationship between voids in mineral aggregate (VMA) and voids filled with bitumen (VFB), it was found that 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.
2. The relationship between VMA and mean profile depth (MPD) as surface texture together with Cantabro loss at -20 degree centigrade revealed that both MPD and Cantabro loss clearly tend to increase as with VMA. It was considered that VFB be less than 21% for satisfying Cantabro loss.
3. Judging from the relationship between VFB and permeability, VFB needs 62% or higher for achieving impermeability.
4. 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.
5. According to a full-scale chain raveling APT test, it was found that new mix is superior to the conventional one. In a rutting APT test, however, the new mix is rather susceptible to lose MPD to hot temperatures. This is adversely affected by the increase of bitumen mortar in the new mix.
6. In a trial construction comparing the conventional 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.
7. The relationship between VMA and VFB obtained in laboratory data almost matched mix design data from the 13 projects. This was also confirmed in the relationship between VMA and bitumen content in volume.

This new hybrid mix has been already implemented in the nationwide toll motorways under the control of East, Central and West NEXCO. The authors strongly believe that this mix can be a good alternative of porous mix in snowy and cold regions because of its durability.

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2. Kamiya et al. 2008. *Development of Long Lasting Safe and Durable Mix for the Japanese Motorways*. Proceedings of the International ISAP Symposium, Zurich, Switzerland.