한국도로학회 논문집
第8券1號 2006年 3月
pp. 107 ~ 117

Development of Drainage Asphalt Mixture Using Large Size Aggregate and Its Performance on Test Pavement

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Abstract

Recently, there has been a remarkable trend of using aggregates at sizes smaller than 13 mm for drainage asphalt pavement (DAP) in order to reduce the noise generated between vehicle tires and road surface. These DAPs have their performance and durability seriously worsen after several years in-service due to the clogging of void space and the abrasion. This paper proposes the use of large size aggregates in porous asphalt mixtures to overcome these defects. Results of laboratory and field experiments on asphalt mixtures with several aggregate gradations are investigated and compared. The study focuses on advantages of DAP using large size aggregate and on particle size combinations containing no fine aggregates of size 2.36 mm or less, which have not been considered in current engineering practice.

INTRODUCTION

Asphalt pavements have been usually constructed using dense graded mixtures for the surface course to drain water off the road surface that prevents problems such as decreases in bearing capacity of the base course and the subgrade caused by rain permeation. In recent years, however, it was developed a new method named as "drainage asphalt pavement" (DAP) or "roadway permeable pavement" (so-called "open graded friction course", OGFC, in the US). DAPs have been extensively used for surface course through numerous trial and error attempts [1].

DAPs have efficient features such as reduction of splash and spray behind vehicles, prevention of hydroplaning, enhanced visibility during night time and rainy weather, and competence for reducing traffic noise. On the contrary, after several years sustaining high traffic volume, DAPs raise problems such as decreases of drainage function and noise reduction capacity due to the clogging of void space and the abrasion. DAPs also require high-quality asphalt binder with high viscosity and durability because the mixtures have so large air voids that their performance can be easily affected by rain

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water permeation and sunlight exposure. As a result, the construction cost of DAPs is known about 1.3 times or so compared to that of conventional asphalt pavements. Taking this issue into account, it is most desirable that the durability of DAPs can be improved not only by using high-quality asphalt binder but also by making use of proper aggregates for the asphalt mixtures, which helps to dissolve the problem of clogging of void space.

This paper presents investigations on effects of using large size aggregates in drainage asphalt mixtures. Through laboratory experiments, the mixtures were found to satisfy the concerned objectives to a certain extent. To examine the performance of one of these mixtures in practice, its test execution was also conducted on an in-service national road.

LABORATORY EXPERIMENTS

In Japan, the proposed DAP technical guideline recommends a standard gradation of drainage mixtures. However, after years in-service DAPs constructed according to this guideline have functional deteriorations due to the clogging of void space and the abrasion as mentioned above. This study suggests the use of large size aggregate mixtures (LSAMs), which have maximum aggregate sizes larger than the usual size of 10~13 mm, as prevention of the problems. Various aggregate gradations were considered for the mixtures.

Concerning the construction practice, the asphalt plant capacity and the construction machinery ability, maximum aggregate size less than 38 mm was examined, which was significantly larger than the maximum aggregate size of 20 mm in common use for asphalt mixtures of the surface course.

Table 1. Gradations Used in the Study

Sieve Size mm	Percent Aggregate Passing by Weight						
37.5	100.0			100.0			
31.5	91.7	100.0		84.0	100.0		
26.5	84.1	91.7	100.0	70.7	84.1	100.0	
19.0	71.2	77.7	84.7	50.7	60.3	71.7	
13.2	59.3	64.7	70.6	35.2	41.9	49.8	100.0
4.75	35.6	38.5	42.3	12.7	15.1	17.9	34.0
2.36	0	0	0	6.3	7.5	8.9	17.0
0.6				1.6	1.9	2.3	5.0
0.3				0.8	1.0	1.1	3.0
0.15				0.4	0.5	0.6	2.0
0.075				0.2	0.2	0.3	1.0
Name	**N38**	**N32**	**N27**	**S38**	**S32**	**S27**	**S13**

Note : Gradation is not containing filler(filler)

Stability of asphalt mixtures depends on the engagement degree of aggregates used in the mixtures. So far, asphalt mixtures have always contained fine aggregates of less than 2.36 mm. There were no studies or construction cases that used mixtures with no fine aggregates. However, when the large size aggregates are used for the asphalt mixtures, it is uncertain whether the small size aggregates would fasten the engagement degree of the aggregates or they would act as sliding bearings between large size aggregates. Accordingly, this paper compared asphalt mixtures with maximum aggregate size less than 38mm in case fine aggregates were used and in case the crushed stone No.7 was used instead.

Examined aggregate gradations

Numerous aggregate gradations can be set for asphalt mixtures. There are also recommended gradation curves for LSAMs by the Ministry of Land, Infrastructure and Transport of Japan. Since these aggregate gradations are not intended for drainable asphalt mixtures, it was decided to set original gradations for the experiments. Six gradations and their code names, which were set based on the Fuller curve, are described in Table 1. Gradations containing fine aggregates were denoted with "S" in their names and those with no fine aggregates were denoted with "N". The amount of filler was 6 % with LSAM and 5 % with standard drainable mixture (S13, maximum aggregate size of 13 mm). Even each of these original gradation sets were hardly verified to be the best gradation at its maximum aggregate size, the gradation set is supposed to be reasonably close to the best.

The optimum asphalt binder content

The optimum asphalt contents for the six original LSAMs were examined with the adhesion test (JHS 234-1992) and the Cantabro test (JHS 232-1992). Figure 1 shows results of the adhesion test with the asphalt content varying from 2.0 % to 4.0 % by weight of the total mix. The adhesion loss of all mixtures increases when the asphalt content increases. Drastic change of the increase gradients is observed at an asphalt content of 3.0 %. Results of the Cantabro test are shown in Figure 2. It is obvious that

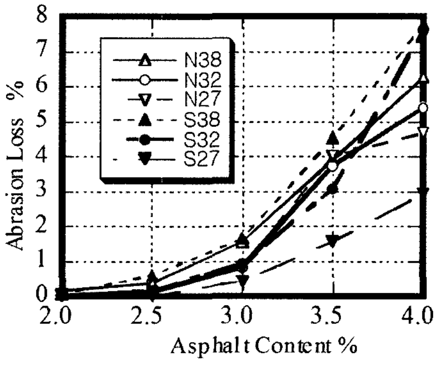


Figure 1. Abrasion Loss vs Asphalt Content in the Adhesion Test

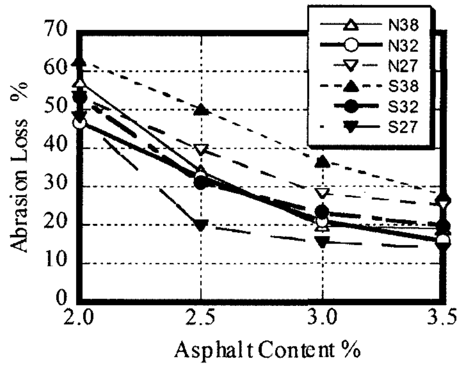


Figure 2. Abrasion Loss vs Asphalt Content in the Cantabro Adhesion Test

the abrasion loss decreases as the asphalt content increases with the asphalt content of 2.5~3.0 %. The abrasion losses of the S38 and the N27 are significantly larger than other mixtures, especially in case of the S38 which appears not worth for setting the optimum asphalt content. According to these experimental results, the optimum asphalt content for all mixtures, except for the S38, can be taken as 3.0 %. Even it is concerned that the optimum asphalt content might be different to a certain extent between mixtures with fine aggregates and mixtures without fine aggregates, no apparent difference was indicated by the results. The optimum asphalt content of 3.0 % is considerably less than values of 4.5~5.5 % of the standard drainable mixtures. It is because the aggregate surface area, in other words the asphalt adherent area, becomes smaller with the use of large size aggregates.

Table 2 shows the adhesion loss and abrasion loss at the optimum asphalt content of 3.0 %. Other experimental results including the large-sized Marshall stability, flow value, specific gravity and air void are also given in the table for reference. It is found that the adhesion loss increases with the increase of the maximum aggregate size of the

Table 2. Test Results and Optimum Asphalt Contents with each Mixture

Name	Optimum Asphalt Contents %	Adhesion Loss %	Cantabro Abrasion Loss %	Marshall Stability kgf(kN)	Flow Value 1/100cm	Specific Gravity g/cm^3	Air Voids %
N38	3.0	1.55	19.6	1325(12.5)	33.7	1.961	24.2
N32	3.0	0.83	21.3	1103(10.8)	26.7	1.980	23.6
N27	3.0	0.82	28.3	1070(10.5)	25.3	1.904	26.5
S38*	3.0	1.65	36.4	1344(13.2)	34.1	2.009	21.9
S32	3.0	0.93	23.2	1307(12.8)	39.0	2.001	22.2
S27	3.0	0.42	15.5	1140(11.2)	29.7	1.987	23.3

※ S38 is reference data

mixtures. Similar tendency is observed for the abrasion loss of mixtures containing fine aggregates, but for mixtures without fine aggregates the abrasion loss decreases when the maximum aggregate size increases. Since this test is aimed at evaluating the scatter resistance of drainable asphalt mixtures, it is inferable, in spite of some dispersion, that mixtures containing no fine aggregates have scatter resistance of aggregates superior to that of the mixtures containing fine aggregates.

Based on examination of the above test results, the following experiments were carried out on two mixtures containing fine aggregates S32 and S27, and two mixtures containing no fine aggregates N38 and N32. These mixtures were compared with a standard drainable mixture S13 that had maximum aggregate size of 13 mm. The gradation for the S13 is set in the middle of grading limits given by the proposed technical guideline and optimum asphalt content of the mixture was taken as 4.5 % based on laboratory tests.

Experiment for sound absorption

Two cylindrical specimens of each of the four LSAMs and three specimens of the S13, which had dimensions of Φ9.80x6.35 cm, were prepared by the standard Marshall compactor. The sound absorption coefficient of the specimens was measured by the tube method (JIS A 1405). Test results of all specimens exhibit typical feature of DAPs with peak values at 630 Hz on the curve of correlation between the sound absorption coefficient and the frequency. Figure 3 shows the correlation between the sound absorption coefficient and the percentage of air voids at the peak values. The LSAMs, except for the S27, give the highest sound absorption coefficients of about 0.85 at around 20 % of air voids while the S13 gives a lower sound absorption coefficient of about 0.78 % at 20.3 % of mean air voids. Values of 0.20 (at 13.8 % of air voids) and 0.73 (at 21.0 % of air voids) were reported by Kawamata [2] through tests using a similar experimental method.

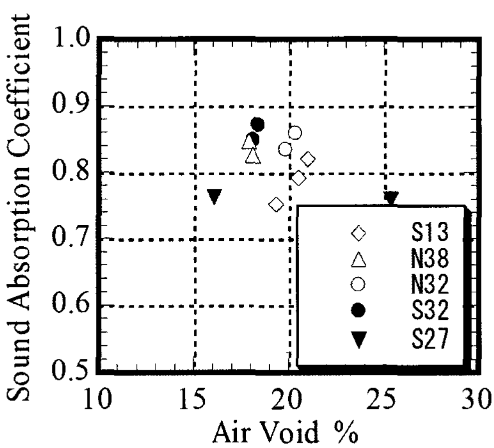


Figure 3. Sound Absorption Coefficient vs Air Voids by Tube Method(JIS A 1405)

It has been reported that the smaller the maximum aggregate size, the less the generated traffic noise. In addition, SandBerg [3] suggested that porous pavements for low-noise road surface are desirable to have surface texture with close arranging aggregates of maximum size less than 8 mm. According to these reports, it is of concern to us what extent of sound absorption coefficients are exhibited and how much traffic noise is generated in cases of the LSAMs compare to the 13 mm drainable mixture. As far as the noise generated by traveling is set aside and only the sound absorption coefficient is considered, the described experimental results show that asphalt mixtures using large size aggregates with a proper gradation are comparable with the standard 13 mm drainable mixture and can be used in practice.

Experiment for permeability

Falling head permeability test

Falling head permeability test was performed to evaluate the permeable function of LSAMs. The cylindrical specimens were dimensions of Φ15.24x9.53 cm, prepared by the large-sized Marshall compactor. After compacted, the specimens were left in the molds and the collars were attached to upper side of the molds. Water was poured into the collar and elapsing time was observed while water level above the mixture surface decreased from 5 cm to 0 cm. The calculated coefficients of permeability for LSAMs, as indicated in Figure 4, are larger than the expected value 1.0×10^{-2} cm/sec of DAPs. In Figure 4, the LSAMs are also revealed having permeable function superior to the S13 mixture.

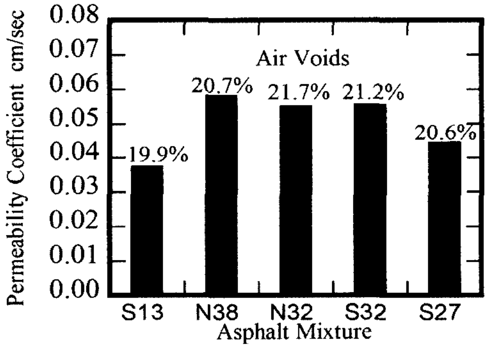


Figure 4. Coefficient of Permeability in the Falling Head Permeability Test

Permeability test after the clogging of void space

DAPs usually have permeable function worn out by the clogging and collapse of void space. To reproduce the clogging condition, a water solution with 10 % gypsum was poured into the upper space enclosed by the collar over the specimen. After the solution fully permeated through the specimen, the falling head permeability test was performed. Figure 5 shows results of the permeability tests on the specimens after the void space clogging. After void space clogging, the coefficient of permeability of the LSAMs remained higher than the expected value of DAPs. Besides, it is observed a general tendency that the "N" mixtures have almost the same permeable function as the "S" mixtures, both before and after the void space clogging.

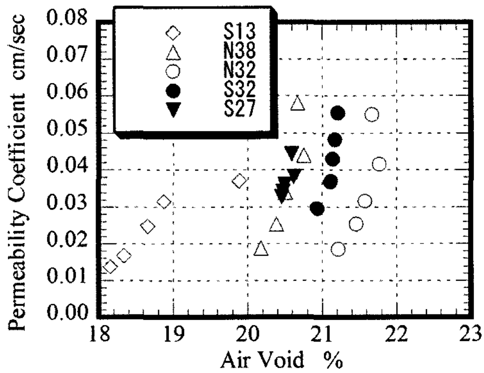


Figure 5. Coefficient of Permeability vs Air Voids in the Permeability Test after the Void Space Clogs

Permeability test after the void space collapses

Specimens with dimensions of 30x30x10 cm were prepared for the Wheel Tracking test. The permeability field test equipment developed by the Road Preservation Technical Center (Japan) was used for permeability tests on specimens after the void space collapsed. Figure 6 shows results of permeability tests on primary specimens and on specimens that had experienced 1 to 5 traverse applications (1 hour for 1 traveling compaction). The S27 and the S32 mixtures, which contained fine aggregates, had permeability decreasing significantly after loaded, and almost lost their permeable function after 3 traverse applications. The S13 mixture also lost its permeable function after 2 traverse applications. Nevertheless, the N32 and the N38, which contain no fine aggregates, survived with quite satisfactory permeability even after 5 traverse applications. The remained permeable volumes of these mixtures are comparable with permeable volumes of primary specimens of other mixtures.

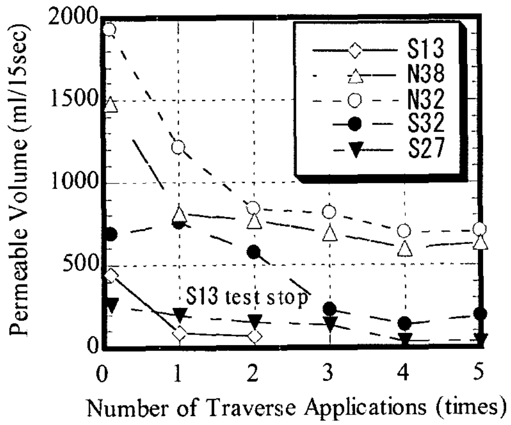


Figure 6. Permeable Volume by the WT Test

Fine aggregates (natural sand) used for asphalt mixtures are usually considered to provide a specific aggregate gradation. However, it is inferred from the above test results that LSAMs with fine aggregates are more susceptible to void space collapsing and can hardly preserve the effective void space when they are subjected to heavy traffic loading. In other words, under repeated loading rounded fine aggregate grains serve as sliding bearings between the coarse aggregate grains and ease the collapse of void space.

Experiment for durability

Wheel Tracking test

Wheel Tracking tests was performed to examine the fluidity-resistance of the LSAMs. Primary specimens and specimens that had void space collapsed after traverse applications were used for the tests. Figure7 compares the dynamic stability of the specimens. As for specimens experienced traverse applications the test results are not quite accurate because deformation of the specimens in the test is extremely small. The increase of dynamic stability of specimens before and after traverse applications is 10 times for the S13 mixture and from 2.5 to 4 times for the LSAMs.

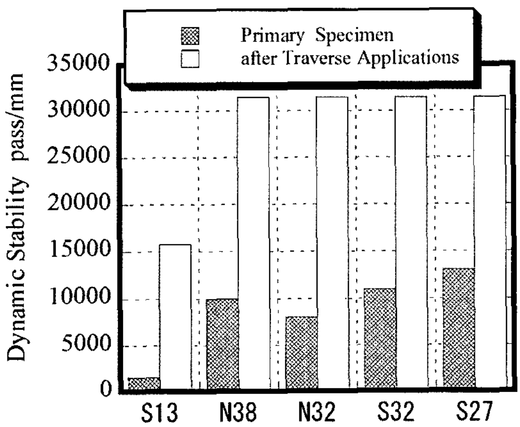


Figure 7. Dynamic Stability by the WT Test

Raveling test

When DAPs are constructed in cold regions, the functional deterioration is known to proceed more rapidly than in normal condition. It is because of the use of tire chains that will ravel off the road surface and produce more dust, which clogs the void space. The wear-resistance and the scatter-resistance of the LSAMs were concerned to be inferior to those of the S13 because the LSAMs contain significantly less asphalt. The reciprocating chain type raveling tests were performed to clarify the concerns. Specimens of dimension 30x15x5 cm were used and the testing temperature was set to -10℃

Figure 8 shows the abrasion amounts measured in the raveling test. The abrasion amounts of the LSAMs containing fine aggregates, the S32 and the S27, are reasonably small while those of the N38 and the N32 are bigger and almost equal to that of the S13. Accordingly, LSAMs that do not contain fine aggregates appear not inferior to the standard drainable mixture S13.

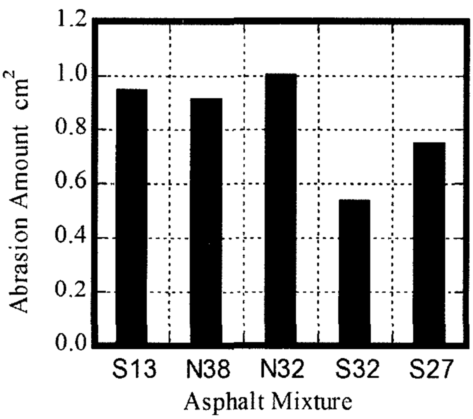


Figure 8. Amount of Abrasion by the Ravelling Test

Summary of the laboratory tests

Based on results of the laboratory tests, it is verified that the LSAMs (N38, N32, S32 and S27) are superior to the standard 13 mm drainable mixture S13 in respects of sound absorption, permeable function and fluidity-resistance. Among the LSAMs, the S32 and the S27 mixtures are superior only in the raveling test, meanwhile, the N38 and the N32 mixtures are superior in resistance against functional deteriorations caused by the void space clogging. In addition, visual inspection of specimen surface after prepared reveals fairly deep-grained surface of the N32 specimens to the other LSAMs. The difference was found remarkable when the specimens were compacted by tampers and rollers.

PLANT EXPERIMENTS

Gradation of the asphalt mixture used in test execution on the pavement is based on the N32 mixture, which has maximum aggregate size of 31.5 mm and does not contain fine aggregates at sizes less than 2.36 mm. However, at the construction site, the N32 mixture was prepared with small size aggregates made from crushed stone No.7, thus, it contained a little portion of fine aggregates at sizes less than 2.36 mm. The high viscosity polymer modified asphalt binder, which is commonly used for DAPs, was used for the mixture. Several tests were performed to determine the optimum asphalt content before the mixture was made for the test execution.

Composite aggregate gradation curve

The composite aggregate gradation of the mixture used for the test execution is shown in Figure 9. The amount of fine aggregate at sizes less than 2.36 mm (from crushed stone No.7) was 3.2 % and the amount of filler was set at 6 %.

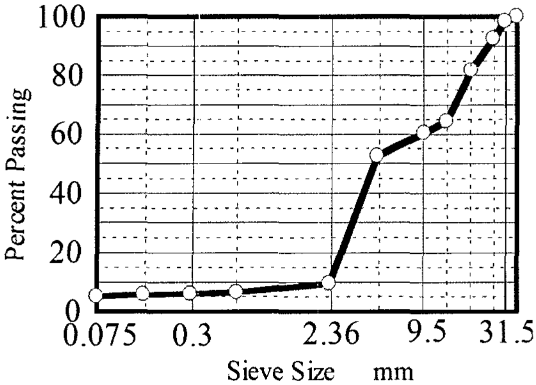


Figure 9. Gradation of LSAM(N38) Field Test

Setting the optimum asphalt content

Figure 10 shows test results of the adhesion loss for asphalt mixtures using the gradation in Figure 9 and with the asphalt content in the range from 2.0 % to 4.0 %. According to the correlation curve between the asphalt content and the adhesion loss, the maximum asphalt content that keeps the static state of the mixture, i.e. the optimum asphalt content, is 3.0 %. This value is identical to the optimum asphalt content found in the laboratory tests described above.

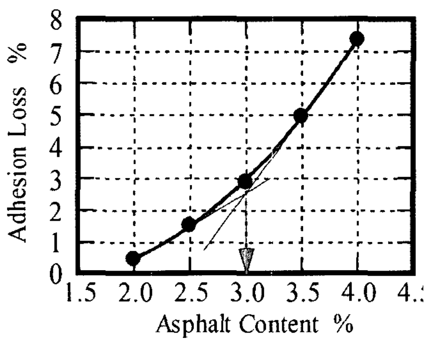


Figure 10. Adhesion Loss vs Asphalt Contents

Material tests of the mixture

Results of the dynamic stability test and the Marshall test on the selected mixture (3 % asphalt content) are summarized in Table 3. Again, the measured values are almost the same as those of the laboratory tests.

Table 3. Properties of N32

Property		Value
Densit	(g/cm^3)	1.984
Maximum Theoretical Density	(g/cm^3)	2.594
Air Voids	(%)	23.5
Stability	(kN)	13.57
Flow Value	(1/100cm)	25
Residual Stability	(%)	93.0
Dynamic Stability	(pass/mm)	9000
Cantabro Abrasion Loss	(%)	20.1

Segregation of aggregate

Figure 11 shows the observed segregative condition of the aggregates when the mixture was produced at the construction site and was just discharged from the dump track. Because the LSAM did not contain fine aggregates and had extremely few asphalt content, the large size aggregates of the mixture was more segregative than the usual asphalt mixtures when they were discharged from the dump track. With visual inspection, it was one of the concerned issues at the time that the mixture tended

Figure 11. The Scattered Condition of the Aggregates discharged from the Dump Track

to scatter around to some extent. At finish of the mixture paving, this concern turned out unnecessary as the mixture was paved and leveled off equally without noticeable segregation of the large size aggregates at the edge. Worry for the dullness of the mixture in construction practice, since no dullness-proof vegetable fiber was added, was also found nominal.

TEST EXECUTION

The site for test execution was at a section of the route 168 (B traffic) in Osaka Prefecture, Katano City. It was a 159 m maintenance work section with a two-lane road, 6 m in width. After 7 cm out of the 10 cm-thick upper layer of the previous asphalt pavement was cut and removed, a 7 cm-thick surface course of DAP was constructed using the LASM (N32). For comparison purpose, replacing pavement with surface course of 5 cm-thick dense-graded asphalt mixture and base course of 5 cm-thick coarse-graded asphalt mixture was constructed for another 51 m-long section at the same site simultaneously.

Permeability evaluation

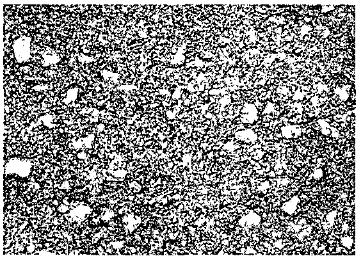
Permeability of the tested pavement was measured at two positions using the public corporation type field permeability test equipment. The maximum result was 1085 ml/15sec and the minimum value was 1015 ml/15sec. The average value of the 6 tests was 1050 ml/15sec. This permeability is higher than the expected value recommended by the DAP technical guideline, 900 ml/15sec, and the required value 1000 ml/15sec given by the technical standard for pavement structures.

Skid- resistance evaluation

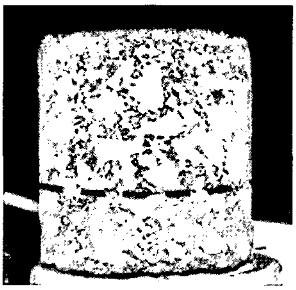
BPN on the road surface measured by the portable skid-resistance tester was 66 at temperature of 5 ℃. After temperature adjusting to 20 ℃, the revised BPN is 55 which is slightly smaller than the common value but appears to raise no influential problem.

Texture evaluation

The laser sensor (MTM) was used to inspect the grain-depth (texture) of the road surface along the vehicle traveling track. The result was 0.49 mm by OWT. According to the apprehension of Oketani [4] for measurements of MTM, it was confirmed that OWT value of 0.8~0.4 mm for DAP having 13~8 mm maximum aggregate size and reasonable fine texture exhibited a tendency to generate low traffic noise. Figure 12 shows photographs of the road



Road Surface State



Roadway Core Sample

Figure 12. Photographs of the Road Surface and the Core Sample of test Execution Site

surface condition and of the roadway core sample taken at the construction site.

Tire/road surface noise evaluation

Noise level generated by rack car driven at speed of 50 km/h on DAPs with maximum aggregate size of 13~5 mm was noted about 90~87 dB and that on ordinary dense-graded asphalt pavements was about 95~93 dB. At this field experiment, the noise survey was carried out with the original measuring vehicle of Maeda Road company as described in Figure 13. The measured noise levels are shown in Figure 14. In this figure, it is also added the noise level of the 13 mm DAP measured at another experimental site where the paving had been carried out at the same time with the tested pavements.

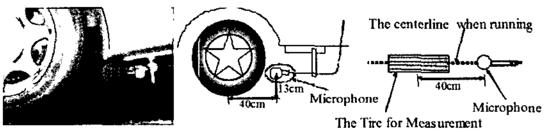


Figure 13. Measuring Vehicle and Schematics Illustration

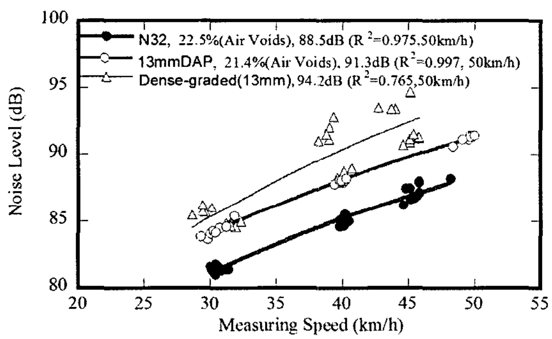


Figure 14. Noise Level vs Measuring Speed

Because the experimental section was located on a moderate curve of the road, it was difficult to maintain the driving speed at the expected value of 50 km/h. The tests were carried out at driving speeds less than 50km/h and the results, as shown in Figure 14, reveal an increase tendency of the generated traffic noise with the increase of driving speed. The comparison also indicates that the traffic noise generated on drainable pavement of LSAM (N32) is about 3.0 dB lower than that of the 13 mm DAP, which is also about 3.0 dB lower than the noise generated on the ordinary dense-graded asphalt pavement.

It is usually apprehended that the traffic noise generated on asphalt pavements will increase with the increase of maximum aggregate size of the asphalt mixture. One of the factors is the reflected sound caused by the large surface area of individual aggregate exposed on the road surface and the other factor is the fricative sound caused between tires and aggregates. Thus, it was questioned why the pavement with LSAM (N32) used in the test execution induced traffic noise lower than one induced than the 13mm DAP. An appropriate rationale for this phenomenon would be the finished fine texture surface of the constructed pavement as shown in Figure 12. With fine aggregates of crushed stone No.7 filling up to large size aggregate-on-large size aggregate porosity, the finished pavement surface of the LSAM acquired a fine surface texture as like as that of 5 mm DAP.

SUMMARY

Results of the laboratory tests and test execution manifest superiorities over the commonly-used 13 mm DAP of large size aggregate mixtures of which a representative instance is the N32 mixture having maximum aggregate size of 31.5 mm and containing no fine aggregates. Further studies will be conducted to verify and enhance the applicability of large size aggregate mixtures into practice construction.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Mr. Yamaguchi and Mr. Nagai, Hirakata Civil Construction Office, Osaka Prefecture, who were authorized to test execution. The authors would like to thank Mr. Nakaichi of Shoken Corp. for his advice, and also the Maeda Road Corp. for the assistance in the combined material test and the functional test at the test construction.

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〈접수:2006. 1. 6〉