DURABILITY OF HIGH-STABILITY ASPHALT MIXTURE UNDER AIRCRAFT LOADING

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INTRODUCTION

Rutting is a major distress mode for airfield asphalt pavements. In Japan, polymer-modified asphalt (PMA) mixtures are often used in the surface course to reduce rutting. However, severe rutting can still occur at intersections of taxiways and at the ends of runways, where aircraft stops temporarily or taxi. Although concrete paving is considered to be an effective countermeasure against rutting, tight time and space constraints make it difficult to apply where it is needed because most airports are unable to provide alternate runways or taxiways for takeoff and landing while the pavement is curing. Thus, the development of materials that have a higher resistance to rutting and overnight serviceability remains a technical challenge.

The authors have developed a high-stability asphalt (HSA) mixture [1]. The newly developed asphalt is composed of a special thermoplastic resin, shown in Figure 1, and an asphalt modified with styrene-butadiene-styrene block copolymer (SBS). It has a high resistance to rutting, and oil and can be applied using the same construction procedure used for conventional hot mix asphalt mixtures in Japan. The unit price of the HSA mixture is about three times as high as that of the straight asphalt (SA) mixture. Although the rutting resistance under vehicle loading has been found to be equal to a semi-flexible pavement material, which is an open-graded asphalt mixture filled with a cement grout, little is known about the durability such as the rutting resistance and groove stability under aircraft loading. In order to investigate the durability of the HSA mixture, we carried out laboratory tests involving simulated aircraft loading. A full-scale loading test was then performed in order to confirm the results of the laboratory tests.

The present paper describes the results of a series of tests performed in order to clarify the fundamental properties of the mixture under aircraft loading.

Figure 1. Special thermoplastic resin

LABORATORY TESTS

Rutting Resistance

Test Method

Rutting resistance was evaluated by means of a wheel tracking (WT) test using the device shown in Figure 2. It is based on a device developed at the Transport and Road Research Laboratory and is equipped with a wheel that applies a load as it traverses the test specimen.

Table 1 shows the test conditions. Although WT tests are commonly conducted under standard load conditions that simulate vehicle loading on road pavement, in the present study, the load was increased 2.5 times in order to simulate the heavy loading of an aircraft. During the tests, the rutting resistance was evaluated based on permanent deformation in the vertical direction after a testing time of 60 minutes.

Since the aggregate gradation and asphalt content affect the rutting resistance, the influence of the aggregate gradation and mixing ratio for the special thermoplastic resin was investigated. The test results are described hereinafter.

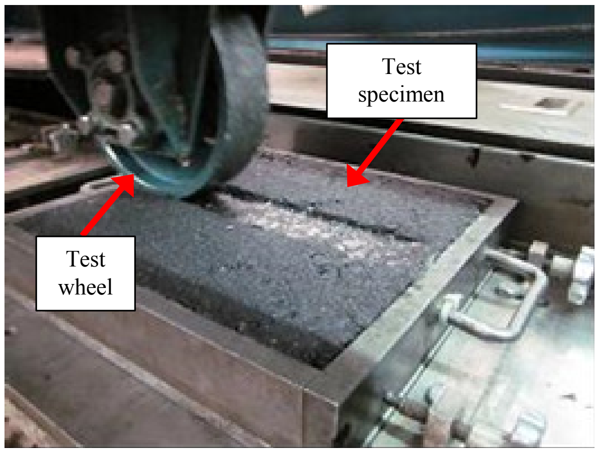


Figure 2. Wheel tracking test device

Table 1. Test conditions

	Standard conditions	Modified conditions
Specimen	H 50 mm, W 300 mm, L 300 mm	
Temperature	60°C	
Load	686 N	1,715 N
Stroke length	230 mm	
Wheel speed	42 passes/min at center point	
Testing time	60 min	

<u>Experiment 1: Effect on rutting resistance of the mixing ratio for the special thermoplastic resin</u>

When using the newly developed HSA mixture in road pavement, 20 wt% of the asphalt content is the special thermoplastic resin and the remaining 80 wt% is asphalt with SBS. Under vehicle loading, the rutting resistance for this mixing ratio has been demonstrated to be equal to that of a semi-flexible material [1]. However, under heavy loading, the HSA mixture might require a higher rutting resistance. Therefore, the rutting resistance of the HSA mixtures with various resin mixing ratios were investigated under heavy loading. The ratios were set to be 20, 25, and 30 wt% considering the ratio for road pavement. Moreover, a semi-flexible material was tested for comparison.

Table 2 shows the design aggregate gradation of the HSA mixture and the semi-flexible material. The HSA mixture was a dense-graded asphalt mixture, and the semi-flexible material was an open-graded asphalt mixture. Table 3 shows the asphalt content of each mixture. The asphalt content was determined using the Marshall design method, which is a general design method used in Japan. This asphalt content is referred to herein as the *optimum asphalt content* (OAC). The semi-flexible material was cured for seven days following injection of the cement grout.

Figure 3 shows the results of the WT test. Permanent deformation decreased as the amount of resin increased. The permanent deformation of the HSA mixture having a resin content of 20 wt% was approximately twice that of the semi-flexible material. A resin content of greater than 25 wt% was needed in order to achieve a rutting resistance equivalent to that of the semi-flexible material under heavy loading.

Table 2. Design aggregate gradation [mm]

Sieve Size	Dense-graded asphalt mixture	Open-graded asphalt mixture
26.5	–	100.0
19.0	100.0	100.0
13.2	96.6	95.9
4.75	44.9	12.0
2.36	42.5	9.8
0.6	28.8	6.9
0.3	16.2	5.9
0.15	9.6	–
0.075	6.9	4.2

Table 3. Asphalt content [%]

Dense-graded asphalt mixture	Open-graded asphalt mixture
5.4	4.7

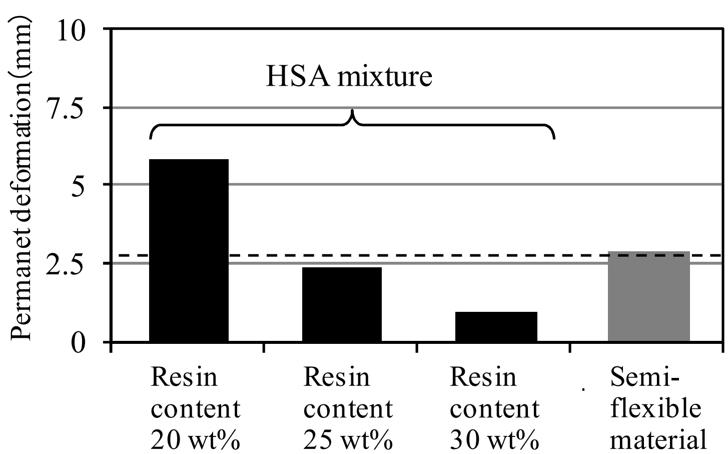


Figure 3. Permanent deformation for various resin mixing ratios

Experiment2: Effect of aggregate gradation on rutting resistance

The aggregate gradation also affects the rutting resistance of an asphalt mixture. HSA mixtures of five different gradations, as shown in Table 4, were tested in order to clarify the effect of the aggregate gradation on the rutting resistance. The PMA mixture, the SA mixture and the semi-flexible material were also evaluated in order to compare the performance of the HSA mixture. Both PMA and SA mixtures are often used in airfield pavement. Table 5 shows the properties of the HSA, PMA, and SA. Table 6 shows the asphalt content of each design gradation. The asphalt content of the three binders was the same for each design gradation. The gradation and asphalt content of the semi-flexible materials are shown in Tables 2 and 3. The resin content of the HSA mixture was set to be 25 wt%, considering the results of Experiment 1 and the degradation of mixing performance with increasing resin content.

Table 4. Design aggregate gradation [mm]

Sieve Size	No.1	No.2	No.3	No.4	No.5
	Coarse-graded asphalt mixture	Dense-graded asphalt mixture	Dense gap-graded asphalt mixture	Dense gap-graded asphalt mixture	Stone matrix asphalt mixture
26.5	100.0	100.0	100.0	-	-
19.0	98.7	98.8	95.8	100.0	100.0
13.2	79.9	82.1	-	96.6	95.6
4.75	45.3	55.2	39.2	44.9	29.2
2.36	27.9	35.7	37.2	42.5	27.1
0.6	17.0	17.4	30.0	28.8	-
0.3	10.4	11.3	16.2	16.2	15.9
0.15	6.7	7.7	9.1	9.6	-
0.075	4.7	5.1	7.0	6.9	10.2

Table 5. Asphalt properties

Index	Unit	HSA	PMA	SA
Softening point	^{o}C	75.0	60.0	48.0
Penetration (25^{o}C)	1/10 mm	29	51	69
Ductility (15^{o}C)	cm	54	100+	100+

Table 6. Asphalt content [%]

No. 1	No. 2	No. 3	No. 4	No. 5
4.6	5.3	5.0	5.4	6.0

Figure 4 shows the results of the WT test. The permanent deformation of the HSA mixtures was approximately 3 mm. There was little difference in the deformation among the five aggregate gradations. The deformation was as large as that for the semi-flexible material. The rutting resistance does not appear to depend on the aggregate gradation in the HSA mixture. Comparing the results for the PMA mixture and the SA mixture, the permanent deformation for the HSA mixture was approximately one-third that of the PMA mixture and at least one-fifth that for the SA mixture. The tests on the SA mixture were stopped before 60 minutes because the deformations of the mixtures exceeded 20 mm.

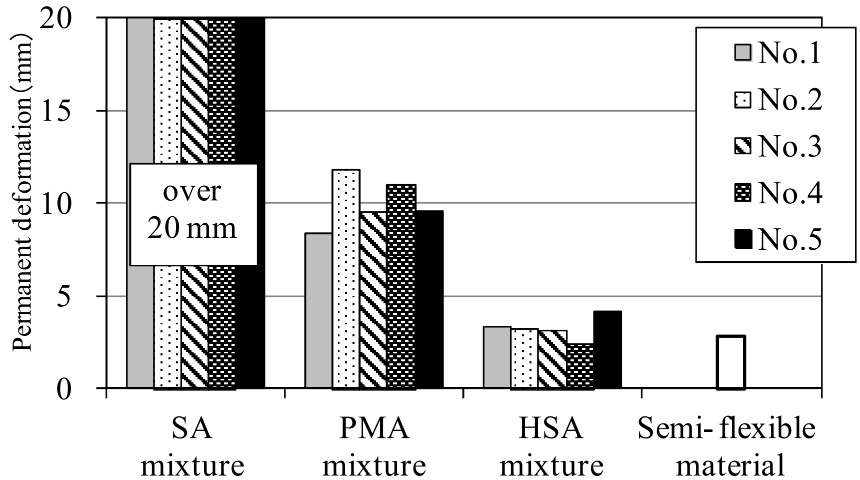


Figure 4. Permanent deformation of mixtures

Groove stability

Materials

In Japan, grooves transverse the runway in order to drain water and prevent hydroplaning. The shape of the grooves is shown in Figure 5. Specimens were cut from the surface course of a test pavement, the surface of which was grooved transversely. The pavement is described in detail hereinafter. The specimens were cut to the same size as the specimens used in the WT test. The test materials were mixtures that include SA, PMA, and HSA. Table 7 and 8 show the design aggregate gradations and asphalt contents of the three mixtures.

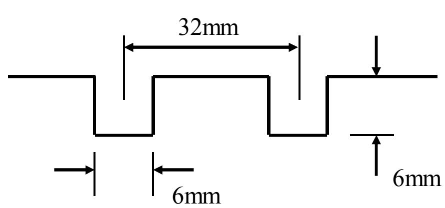


Figure 5. Cross section of the grooves

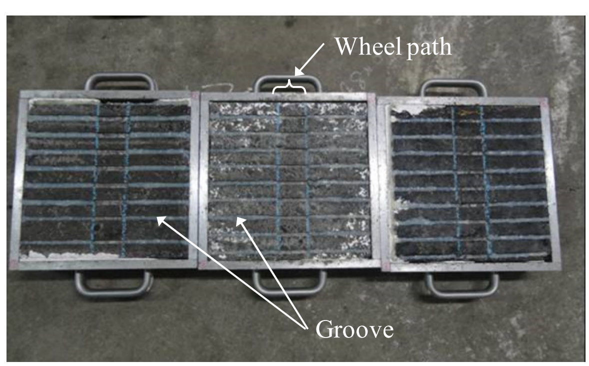


Figure 6. Test specimen

Test Method

The failure modes for the grooves include clogging and edge defects. In the present study, we evaluated the degree of clogging due to repetitive loads, because clogging is considered to greatly affect the drainage performance of runways. Repeated loading tests were carried out using the WT test device shown in Figure 1. The test conditions are also listed in Table 1. The degree of clogging was evaluated by the residual ratio of the groove volume. The residual ratio is the ratio of the groove volume after a certain number of wheel passes to the groove volume before testing, and is expressed as follows:

$$l = \frac{a'}{a} \times 100\,(\%) \qquad (1)$$

l: Residual ratio of the groove volume, a: Groove volume before the WT test, a': Groove volume after a certain number of wheel passes in the WT test.

The groove volume was measured by pouring sand into the grooves in the wheel path. The sand volume was then converted into the groove volume. The sand volume was measured after 0, 50, 100, 200, 500, 1,000, and 2,000 wheel passes.

Results

Figure 7 shows the residual ratios for various numbers of wheel passes. Figure 8 shows the change in the groove shape during the WT test. The residual ratio for the SA mixture and the PMA mixture was less than 50% after 100 wheel passes. The residual ratio for the SA mixture reached approximately 10 % after 500 wheel passes at which time the grooves fully disappeared (Figure 8). The residual ratio for the PMA mixture was less than 20% after 1,000 wheel passes, at which time the grooves were barely visible. In contrast, the residual ratio for the HSA mixture was 90% after 2,000 wheel passes. The grooves maintained their original shape. Higher groove stability was observed for the HSA mixture as compared to the SA and PMA mixtures.

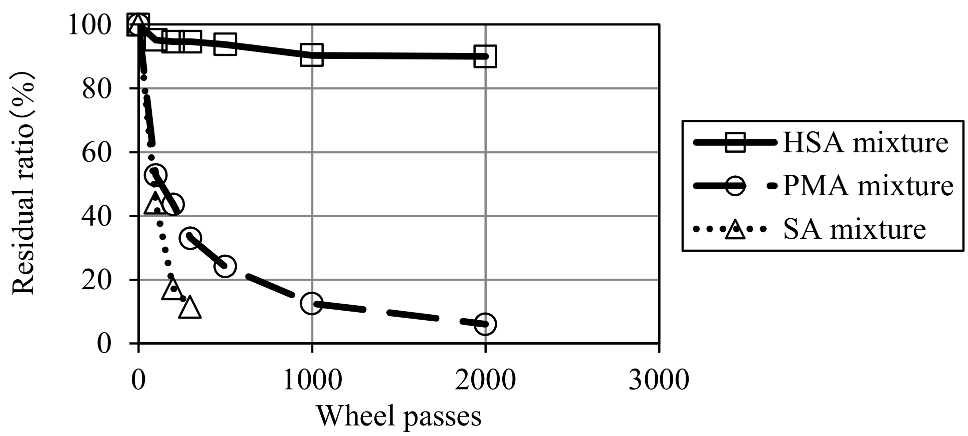
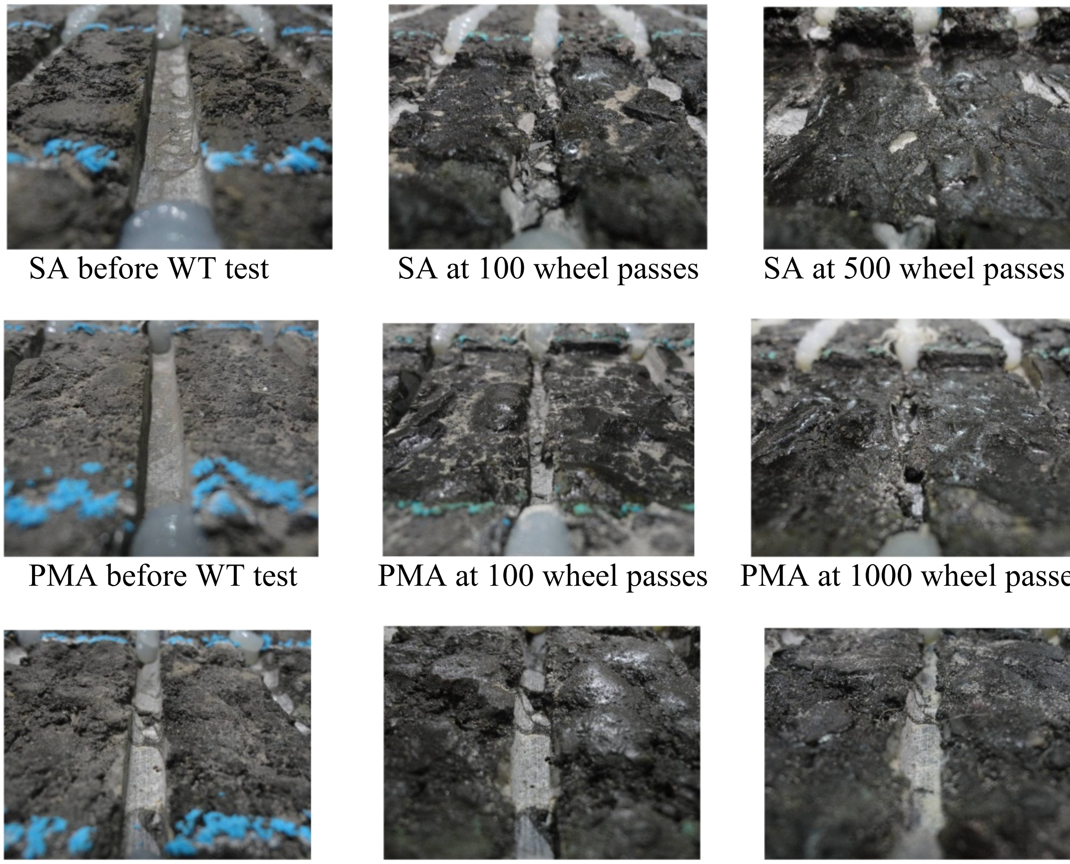


Figure 7. Residual ratio for the groove volume vs. number of wheel passes



SA before WT test | SA at 100 wheel passes | SA at 500 wheel passes

PMA before WT test | PMA at 100 wheel passes | PMA at 1000 wheel passes

HSA before WT test | HSA at 200 wheel passes | HSA at 2000 wheel passes

Figure 8. Change in the shapes of grooves in the WT test

FIELD TEST

Construction of test pavement

The surface course and base course were constructed on existing pavement after it was cut to the depth of the base course. The paving machine and construction procedure were the same as those used in airfield pavement construction. Figure 9 shows the plan and cross section of the pavement. The pavement was divided into three sections. Different materials were used for the surface and base courses. The SA, PMA, and HSA mixtures were used in three different sections, which are referred to hereinafter as the SA, PMA, and HSA sections respectively.

Table 7 shows the design aggregate gradations for each surface and base course layer. The purpose of the gradation is to make the surface and base courses identical to the No.2 and No.1 design gradations used in the laboratory test. The asphalt content of each material was set to the OAC. Table 8 shows the asphalt content of each material. The amount of special thermoplastic resin was designed to be 25 wt% of the asphalt content of the HSA mixture. The remaining 75 wt% of the asphalt content was asphalt with SBS. Grooves were cut into the pavement surface. Figure 5 shows the shape of the grooves.

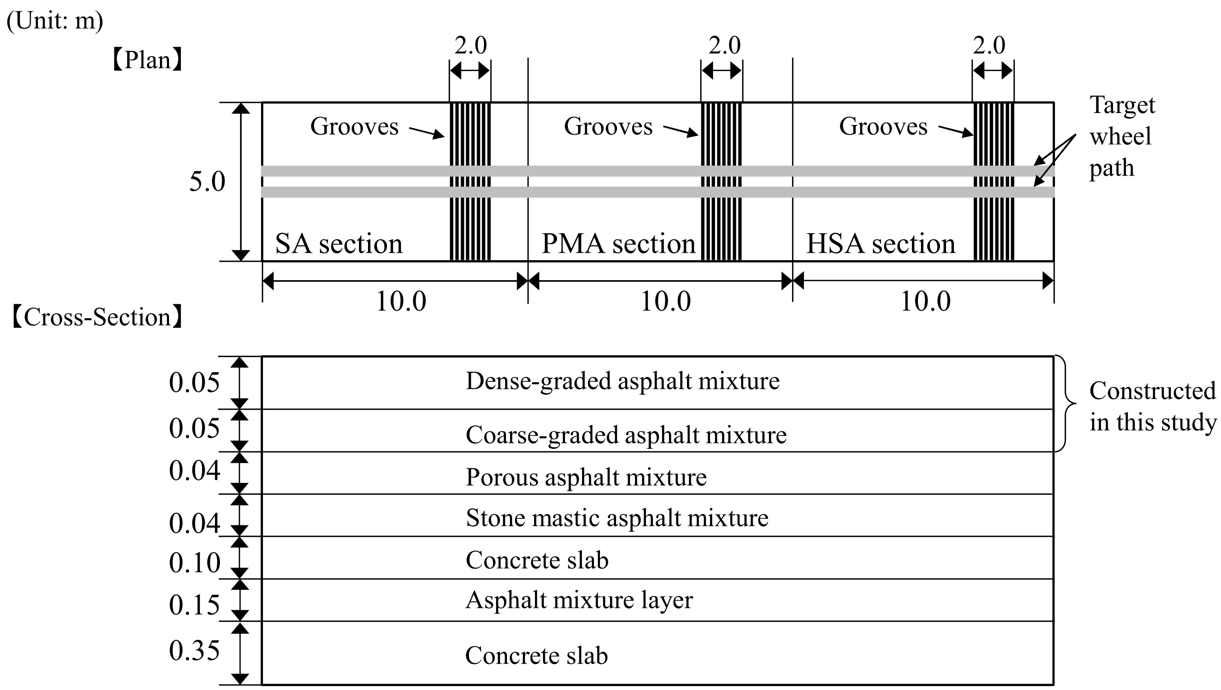


Figure 9. Plan and cross section of the test pavement

Table 7. Design aggregate gradation [mm]

Sieve Size (mm)	No.1	No.2	No.3	No.4
	Surface course of HSA section	Base course of HSA section	Surface course of PMA and SA section	Base course of PMA and SA section
26.5	100.0	100.0	100.0	100.0
19.0	98.9	98.7	98.7	98.6
13.2	82.5	79.1	81.6	80.0
4.75	53.6	48.7	51.4	43.9
2.36	35.9	29.8	34.1	27.7
0.6	21.5	17.3	20.2	16.3
0.3	14.1	13.0	13.8	10.8
0.15	8.1	6.8	7.5	6.4
0.075	5.5	4.3	4.5	4.3

Table 8. Asphalt content [%]

No. 1	No. 2	No. 3	No. 4
Surface course of HSA section	Base course of HSA section	Surface course of PMA and SA sections	Base course of PMA and SA sections
5.2	4.6	5.3	4.9

Marshall stability and bulk density of test pavement

Cylindrical cores were sampled from the test pavement in order to evaluate the Marshall stability and bulk density of each layer, as specified by the Japan Civil Aviation Bureau (JCAB) [2]. The cores were 100 mm in diameter. The test conditions were set as described in Reference [3]. The loading speed for the Marshall stability test was 50 mm/min, and the test temperature was 60°C. Figure 10 shows the Marshall stability for each section. The specification calls for a Marshall stability of 8.8 kN for the surface and base courses. The stability of all sections satisfied the specification. Figure 11 shows the ratio of the actual bulk density of each section to the design bulk density as determined by the Marshall method. The design bulk density was defined as the density of the asphalt mixture compacted by 75-blow Marshall compaction at OAC, where the specification calls for a ratio of the actual bulk density of each section to the design bulk density of 98% for the surface and base courses. Although there are layers in which the ratio did not satisfy the specification in the SA and PMA sections, the ratio for each layer of the HSA section satisfied the specification. The HSA mixture, which has a resin content of 25 wt%, satisfies the specification.

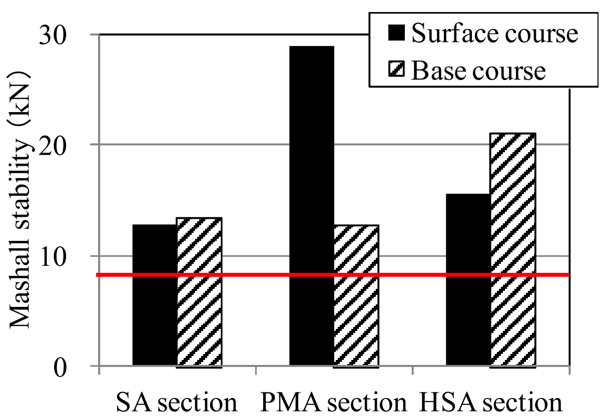


Figure 10. Marshall stability in each section

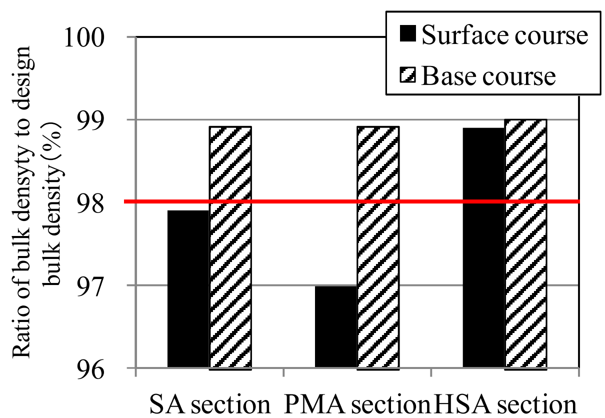


Figure 11. Bulk density in each section

Test Method

A repeated-loading test was performed on the test pavement in order to confirm the results of the laboratory test. The loading vehicle shown in Figure 12 was used in the test. The vehicle was a six-wheeled truck with a trailer. Figure 13 shows the loading wheels of the trailer. The configuration of the loading wheels is the same as that of the main gear of a B747-400. The other wheels of the trailer are safety wheels. The safety wheels were lifted and left unresolved during the test. The load can be adjusted by placing ingots on the trailer bed. The test conditions are listed in Table 9. During the test, the load was adjusted in order to obtain a contact pressure of 1.5 MPa, which is equivalent to the load generated by a large aircraft, such as a B747-400. The traveling speed was approximately 5 km/h, taking into consideration the trailer performance and safety during the test. The maximum number of wheel passes was 600. The rut depth and residual ratio for the groove were evaluated at 0, 40, 80, 200, 320, and 600 wheel passes. The definition of the residual ratio was the same as that for the laboratory tests. However, the volume was calculated based on the groove width and depth as determined using a laser displacement meter. For the measurement of the groove width and depth, a line was selected from each side of the loading wheel path. The widths and depths of 15 grooves were measured in each line. The groove volume was calculated from the average groove width and depth obtained from the two lines.

Figure 12. Loading vehicle

Figure 13. Loading wheels of the trailer

Table 9. Test conditions

Maximum air temperature	24.4°C
Minimum air temperature	18.4 °C
Maximum surface road temperature	41.0 °C
Load	934 kN
Maximum number of wheel passes	600
Number of wheel passes at which rut depth and groove volume	0, 40, 80, 200, 320, and 600

Results

Figure 14 shows the rut depth for each section. Rut depth was approximately 12mm after only 600 passes in the SA section. A possible cause was that the test was conducted on the same line at short time intervals under the full load condition of a B747-400, which is consider to be more severe condition than actual conditions. The rut depths for the PMA section and the HSA section was approximately half that for the SA section. There was little difference in the depth between the PMA section and the HSA section even though the resistance of the HSA mixture was observed to be higher in laboratory tests. These results are thought to be due in part to the difference in the test temperatures between the laboratory and field tests, which were 60°C and approximately 40°C, respectively. Taking into consideration the softening points of PMA (60°C) and HSA (75°C), the PMA mixture also shows a high resistance to rutting if the road surface temperature is approximately 40°C. Moreover, no significant difference was observed because the rut depths in the test were not very large. Since a difference in deformation behavior might occur at higher temperatures in the summer when the surface road temperature reaches approximately 60°C, it is necessary to conduct additional repetitive loadings during the summer in order to evaluate the behavior at high temperatures under the actual conditions of aircraft loading.

Figure 15 shows the residual ratio for the groove volume in each section. In the SA section, the ratio reached approximately 0% after 200 wheel passes, and the grooves disappeared completely. In the PMA section, the ratio was approximately 30% after 600 wheel passes. In the HSA section, on the other hand, the ratio was approximately 60% after 600 wheel passes. The aggregates at the groove edge chipped off significantly during the test of the HSA section. The edge defects are thought to affect the increase in the ratio from 80 to 320 passes because the edge defects increase the groove volume by increasing the width of the grooves. The reason why the defects were only observed in the HSA section was not clear. It is necessary to elucidate the phenomenon because the fragments might be sucked into engines of aircraft. Figure 16 shows the grooves after the test. The deformation in the HSA section was confirmed visually to be smaller than that in the PMA section. The superior groove stability was confirmed in the full-scale loading test.

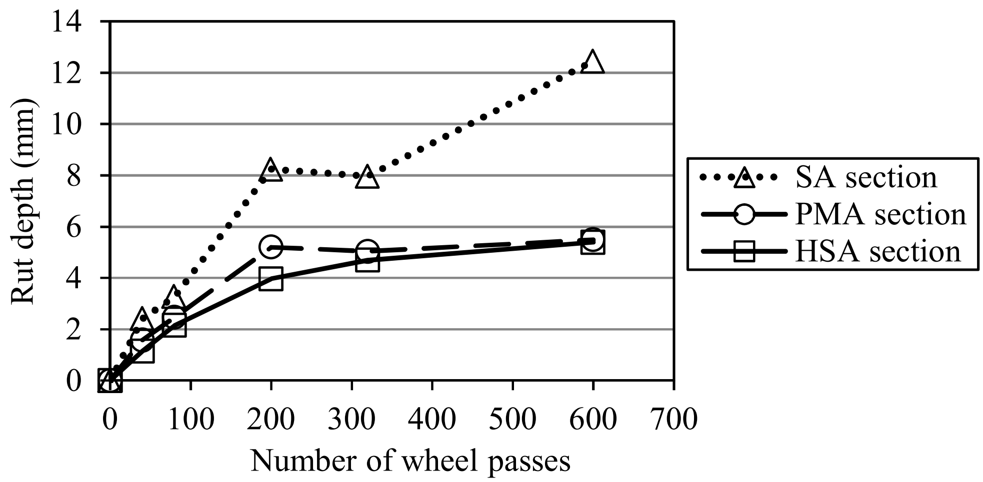


Figure 14. Rut depth vs. number of wheel passes

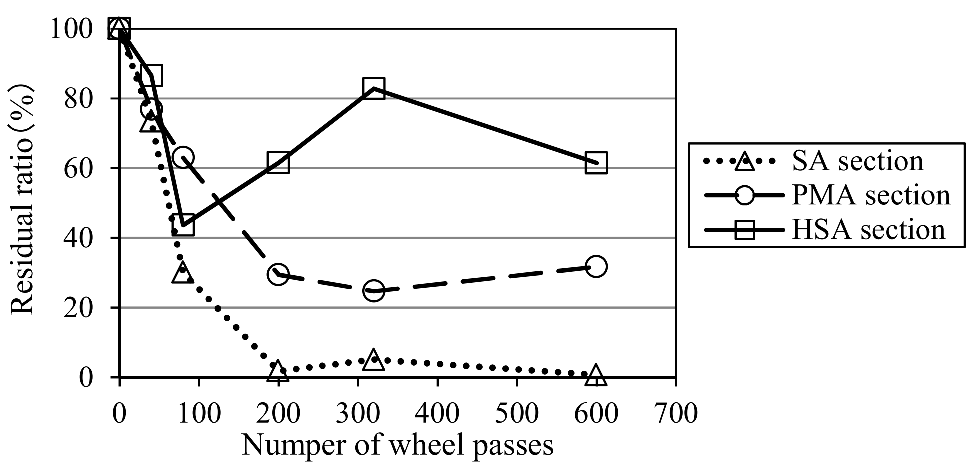
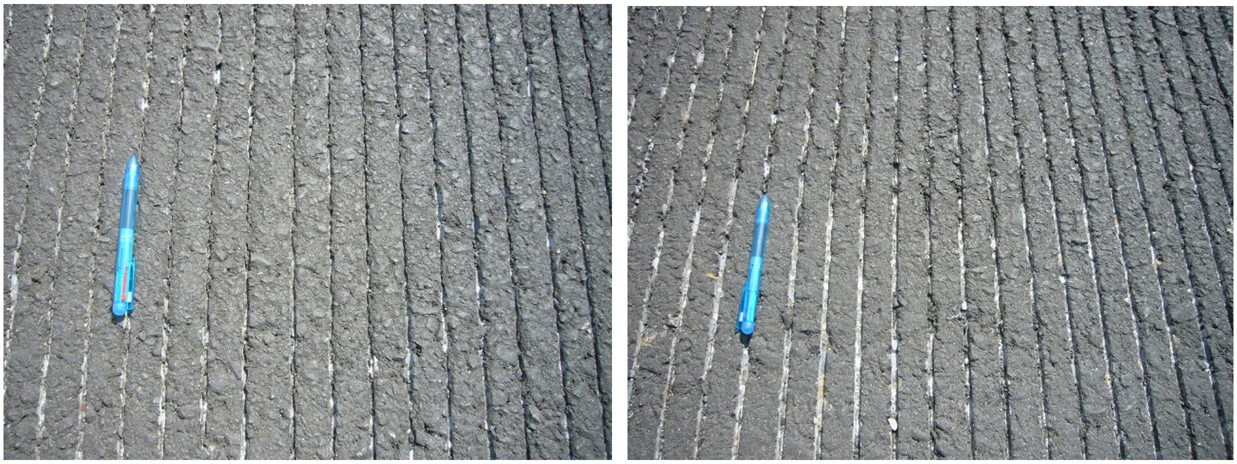


Figure 15. Residual ratio of groove volume vs. number of wheel passes



a) MA section b) HSA section

Figure 16. Grooving after the repeated loading test

CONCLUSION

In order to investigate the durability of a HSA mixture for use as an airfield pavement material, the authors carried out laboratory tests simulating aircraft loading. Full-scale loading tests were then conducted in order to confirm the results of the laboratory tests. The following results were obtained from the series of tests:

1) In the laboratory tests, the amount of special thermoplastic resin required was thought to be more than 25 wt% of the asphalt content in order to achieve sufficient rutting resistance of a semi-flexible pavement material under heavy loading.

2) Permanent deformation in the vertical direction of the HSA mixture, the resin content of which was 25 wt%, could be reduced by one-third compared to that of the PMA mixture under heavy loading in the WT tests.

3) The residual ratio for the groove volume of the HSA mixture was approximately one-ninth that of the PMA mixture in the WT tests. The groove stability of the HSA mixture was found to be higher than that for conventional materials, such as the SA and PMA mixtures.

4) The HSA mixture, whose resin content was 25 wt% of the asphalt content, satisfied the Marshall stability specification and the bulk density requirement for airfield pavement in Japan. The HSA mixture in this content could be applied using the same paving machine and construction procedure as those used for applying airfield pavement.

5) The superior groove stability for the HSA mixture was confirmed through a full-scale loading test. However, there was little difference in the rutting resistance between the HSA mixture and the PMA mixture when the road surface temperature was approximately 40°C. In order to evaluate the behavior at high temperature under actual aircraft loading, it is

necessary to conduct additional repetitive loading testing in summer when the road surface temperature reaches approximately 60^{o}C.

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