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Experimental Study on Airfield Used Asphalt Mixture Designed by Superpave Concept

Kai Su[1+], Ryota Maekawa[2], and Yoshitaka Hachiya[3]

Abstract: Aimed to alleviate the rutting distress in airport pavements, the Superpave concept was introduced to design asphalt mixture in this study. The engineering properties of Superpave mixture were comprehensively investigated compared with the control mixture (currently used typical Marshall mixture in airfield) through a set of laboratory performance-related tests in terms of wheel tracking test, submerged wheel tracking test, raveling test, static bending and flexural fatigue test. The same modified asphalt binder and local materials were used in the two kinds of mixtures. Three aggregate gradations, i.e., fine, coarse, and intermediate, were used for Superpave mixture design. The test results found that the coarse Superpave mixture can meet all the Superior criteria, and exhibited significantly higher resistance to rutting, raveling and similar property in thermal cracking, fatigue and moisture resistance compared with the control mixture. Therefore, this experimental study gave an encouraging result that it was viable to further use this coarse Superpave mixture in airfield for situations where rutting was a major concern.

Key words: *Airport pavements; Asphalt mixture; Engineering property; Superpave.*

General Background

Asphalt mixtures are used in surface layers in a pavement structure to distribute stresses caused by the repeated traffic load applications. To perform this function well over the design life, the mixtures must have enough capacity to resist permanent deformation, cracking (fatigue and thermal), stripping, raveling, and other damages. One of the critical factors of attempting to prevent such failures was by properly designing Hot Mix Asphalt (HMA) mixtures. It was well recognized now that the right combination of asphalt binder and aggregates, i.e., properly proportioned, would result in a stable and acceptable mix that could perform satisfactorily over the intended life [1].

In the history of asphalt mixture design, many methods have been developed from the pat test to the latest Superpave [2]. By far, the most common procedure used in the world to design HMA was the Marshall method, which was originally developed by Bruce Marshall and refined by the U.S. Army Corps of Engineers [1, 3]. However, considerable research indicated that the impact method of laboratory compaction with the Marshall hammer did not simulate mixture densification that occurred in the field. What's more, the strength parameters used in this approach, Marshall Stability and flow, were too empirical and did not directly reflect any pavement performance [4]. Consequently, there had been a growing feeling that a rational procedure should be developed to suit the modern asphalt mixture design.

In 1987, the Strategic Highway Research Program (SHRP) in the USA began developing a new system for specifying asphalt materials. One of the SHRP products was the Superpave mix design system with the key features of laboratory compaction and performance based testing [1]. In this new system, the Superpave Gyration Compactor (SGC) was used to compact HMA specimen, and the Optimal Asphalt Content (OAC) was selected based on 4% air voids at the design gyration number. Since the completion of SHRP in 1993, much attention was paid worldwide to studying and evaluating the asphalt mixtures designed by Superpave, of which, many studies indicated that Superpave mixtures could perform better under various temperature ranges and traffic loads compared with the common Marshall mixtures, more significantly in rutting resistance [5-12]. Meanwhile, some comparative research on the laboratory compaction method was performed between SGC and other compaction methods [13-17]. Results showed that the SGC compactor did a good job of duplicating compaction achieved by roller during the construction and vehicular traffic during service life. Due to its evident advantage, the Superpave mix design procedure steadily gained popularity in road field. In recent years, Superpave use gradually increased for airfield projects in order to meet the enhanced challenge with regard to the large aircrafts and heavy traffic, of which the results from some past application projects had been reported as "very satisfied with the runway's performance" [18, 19].

Until now, the Marshall method was routinely used to design HMA in airfield in Japan. In recent years, with the increased traffic volume and aircraft loads as well as the higher ambient temperature in summer, the runway pavements in some busiest airports frequently suffered severe rutting. According to recent studies, Superpave mixture may be one choice to alleviate this issue in that it could design mixtures with high rutting resistance. However, though the Superpave was well accepted currently, it could not be directly used in a specific traffic and environmental condition without any pre-evaluation. So to use Superpave mixture in a certain airport, an in-depth research was required.

In the last few years, a tentative research has been carried out by

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[1] Airport Researcher Center, Port and Airport Researcher Institute, 3-1-1, Nagase, Yokosuka, 239-0826, Japan.
[2] Airport Researcher Center, Port and Airport Researcher Institute, 3-1-1, Nagase, Yokosuka, 239-0826, Japan.
[3] Service Center of Port Engineering, 3-3-1, Kasumigaseki, Chiyoda-ku, Tokyo, 100-0013, Japan.
[+]Corresponding Author: E-mail xahusuhai@gmail.com

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the authors in an attempt to apply asphalt mixtures designed by Superpave concept in airport pavement [20]. From this earlier study, an encouraging result was obtained that Superpave mixture with a coarse aggregate gradation showed obviously superior rutting resistance to the Marshall designed mixture. However, resistance to cracking, moisture damage, and raveling were equally important in airfields. Thus, to further move it from the laboratory to the airport pavement construction works, the Superpave mixture should be systematically evaluated by the aforementioned performance related tests.

Research Objective and Scope

This study focused on designing the surface course HMA mixture (19*mm* nominal maximum aggregate size) by Superpave concept for use in a heavy duty airport in eastern Japan, followed by the performance evaluation compared with the control mixture through a series of laboratory tests. It was aimed to provide an experimental basis for using Superpave method in airfield.

Experimental Program

Materials and Mixture Design

The crushed sand stone and gravel widely used in airport pavement construction works in Japan were, respectively, used as coarse and fine aggregate in this study and hydrated lime was selected as mineral filler. The properties of aggregates and asphalt used satisfied the specified requirements, which were shown in Table 1 and Table 2, respectively [21].

Here, Superpave was defined as the HMA design process in which the SGC was used to compact samples and the Superpave volumetric criteria was used to select a proper aggregate structure and OAC. As aggregate gradation was an important factor that influenced the performance of asphalt mixture, it should be elaborately selected to achieve a satisfactory performance. For the comparison purpose, three trial aggregate gradations as shown in Fig. 1 were evaluated in the Superpave mix design process, i.e., above the restricted zone, slightly above the restricted zone, and below the restricted zone (respectively, symbolized as gradation A, B, and C) in accordance to the past research [22-24]. As a result, the gradation C similar with that used in the earlier study was finally selected as the aggregate structure [20]. Then, the OAC was determined for mixture with gradation C when this asphalt binder content resulted in 4% air voids at N_{des} (design gyration number). It should be noted that the N_{des} level of 142 used was determined based on the design 7-day maximum air temperature (39°C) in this region and the maximum traffic volume($>1\times10^8$ESAls) according to the Superpave mix design manual, which was reasonably assumed to represent the heavy duty traffic condition in this airport [25].

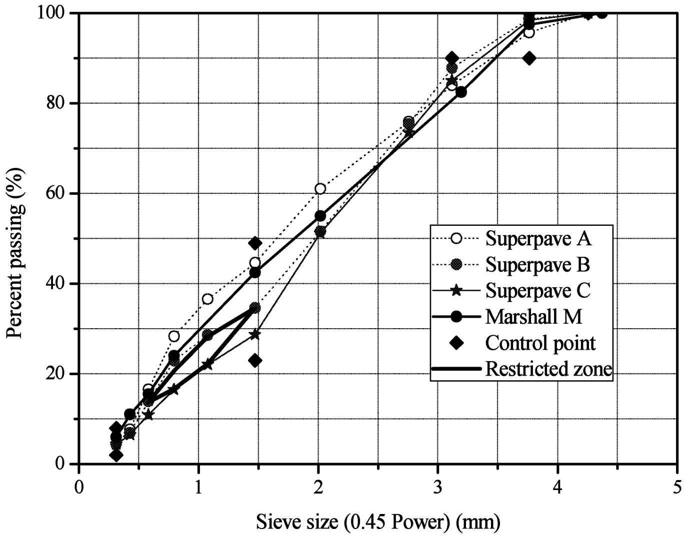

Fig. 1. Gradation Chart of Asphalt Mixtures.

The normally used dense-graded HMA in airfield was used as a control mixture, which had a medium gradation in the specified range as shown in Fig. 1 (denoted as M). It was designed following the general Marshall procedure with 75 blows per side by the standard Marshall hammer.

Test Methods

The engineering properties of Superpave mixture were evaluated compared with the control Marshall Mixture through a series of laboratory tests as described below [26]:

Wheel tracking test was used to determine the deformation resistance of mixtures under high temperature. In this test, the specimen was compacted to 300×300*mm* in cross-section and 50 *mm* in height by a rolling compactor, and then held in an environmental chamber for a minimum of 6hrs at the prescribed

Table 1. Properties of Aggregates and Mineral Filler.

Properties	Bulk Specific Gravity (g/cm^3)			Absorption(%)			L.A. Abrasion (%)	Soundness (%)	Flat & Elongated (%)
	Coarse	Fine	Filler	Coarse	Fine	Filler			
Test Values	2.659	2.709	2.711	0.67	2.31	0.15	12.0	4.8	0.8
Criteria [a]	>2.45		>2.6	<3.0		<1.0	<35%	<12%	<15%

[a] Criteria for asphalt is given in the specification published by the national airport agency, Japan [21].

Table 2. Properties of Polymer Modified Asphalt Binder.

Properties	Softening Point (°C)	Ductility (15°C, *cm*)	Penetration (25°C, 1/10*mm*)	Toughness (25°C, $N \cdot m$)	Tenacity (25°C, $N \cdot m$)	Loss after RTFO (%)
Tested Values	59.5	100+	54	36.5	29.8	0.02
Criteria [a]	≥56.0	≥30	≥40	≥8.0	≥4.0	≤0.6

[a] Criteria for asphalt is given in the specification published by the national airport agency, Japan [21].

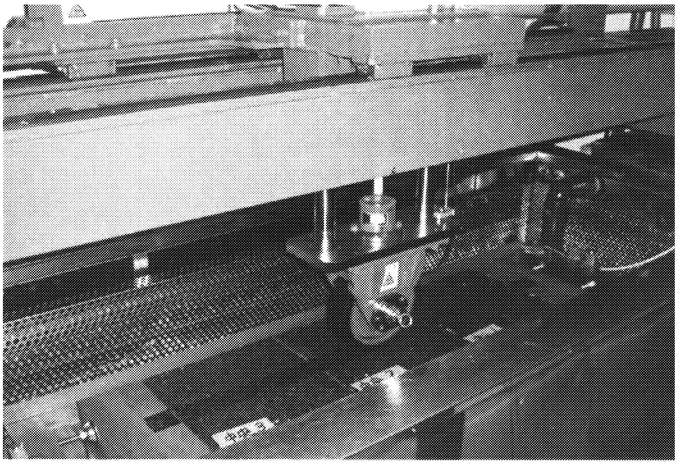

Fig. 2. Wheel Tracking Test.

Fig. 3. Steered Wheel Tracking Test.

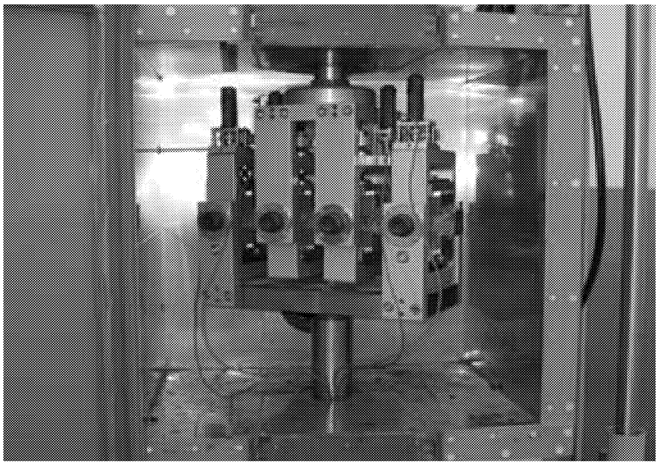

Fig. 4. Flexural Fatigue Bending Test.

Fig. 5. Three Point Bending Test.

temperature of 60˚C to reach the temperature equilibrium. Then as shown in Fig. 2, at 60˚C, a rubber faced tire rolled back and forth across the surface of the dry specimen at the speed of 42passes/min. A high tire-specimen contact pressure of 1.38*MPa* was here used to fully simulate the aircraft (Boeing 747) loading condition. The test was terminated after an hour, and the final vertical deformation was viewed as the indicator of rutting resistance.

Steered wheel tracking test was used to simulate raveling of mixture from the cornering, steering during halting, acceleration, and deceleration of aircrafts. Raveling in airfield was of great concern since it could affect the operation safety. In this test, a solid tire ran on the specimen along a 10*cm* radius with the speed of 10.5revolutions/min by applying a twist to the specimen surface to cause raveling. The test equipment was shown in Fig. 3. The specimen used was same as that in wheel tracking test. The tests were conducted at the temperature of 60˚C and the loss in weight from the specimen was adopted as an index to evaluate raveling resistance.

The moisture susceptibility of HMA mixture was evaluated by the indirect tensile strength (ITS) ratio between the conditioned and unconditioned specimens. For this test, specimens with the diameter of 100*mm* and 95*mm* tall were compacted at about 7% air voids. One subset, consisting of three specimens, was considered as the control set. The other subset of three specimens was conditioned. The conditioned specimens were subjected to partial vacuum saturation followed by 15-hour freeze cycle at 0˚C and by a 24-hour thaw cycle at 60˚C. All specimens were tested to determine their indirect tensile strength. The water sensitivity was determined as a ratio of the average tensile strengths of the conditioned subset divided by the average tensile strengths of the control subset. The Superpave required a minimum tensile strength ratio of 80%.

Four-point flexural fatigue bending test was used to evaluate the fatigue characteristics of HMA mixture as shown in Fig. 4. In this study, the test was strain controlled and the input strain was waveform sinusoidal shape, applied at a frequency of 10*Hz*. The strain level of 400 microstrains was selected because it corresponded approximately to the strain level induced by the Boeing 747 in the typical airport pavement structure. The specimen used had the standard dimension of 300×40×40*mm* in length, width, and height, respectively. This test was conducted at the temperature of 20˚C. Fatigue failure was defined when the stiffness reduced to 50% in initial stiffness.

Simple three point bending tests as shown in Fig. 5 were performed at -10˚C by applying a center point load on the rectangular specimen at a deformation rate of 10*mm/min*. The specimen with the dimension of 300×100*mm* in cross-section and 50*mm* in height was supported at two ends. The strain at failure was used as the indicator of the mixture's resistance to thermal cracking.

Table 3. Estimated Properties of the Trial Superpave Mixtures.

Gradation	Initial	Estimated Properties to Achieve 4% Air Voids at N_{des}						
	AC (%)	AC (%)	VMA (%)	VFA (%)	Dust Proportion	$\%G_{mm}$ @N_{ini}	$\%G_{mm}$ @N_{max}	Specific Gravity
A	4.5	4.2	13.9	71.1	2.3	87.4	96.9	2.412
B	4.5	4.5	14.5	72.4	1.3	89.3	96.8	2.391
C	4.5	5.0	15.1	73.5	1.0	88.6	97.3	2.385
Criteria [b]	-	-	>13	65~75	0.6~1.2	<89%	<98%	-

[b] Criteria is specified in Superpave mix design, Superpave series No. 2 (SP-2) [27].

Table 4. Volumetric Properties of Superpave and Marshall Mixtures at OAC.

Property	VA (%)	AC (%)	VMA (%)	VFA (%)	Dust Proportion	$\%G_{mm}$ @N_{ini}	$\%G_{mm}$ @N_{max}	Specific Gravity
Superpave C	4.0	5.0	15.6	74.7	0.88	88.3	97.4	2.371
Criteria [b]	4.0	-	>13	65~75	0.6~1.2	<89%	<98%	-
Property	VA (%)	AC (%)	VMA (%)	VFA (%)	Stability (*kN*)	Flow (0.1*mm*)		Specific Gravity
Marshall M	3.1	5.4	15.5	80.1	18.11	36		2.378
Criteria [a]	2~5	-	-	75~85	>8.8	20~40		-

[a] Criteria for asphalt is given in the specification published by the national airport agency, Japan [21].

[b] Criteria is specified in Superpave mix design, Superpave series No. 2 (SP-2) [27].

Test Results and Discussion

The Superpave mixture and Marshall Mixture were firstly designed, and then performances of related tests were performed according to the above mentioned methods. Samples were prepared with the optimal asphalt content for both two mixtures. In each test, three specimens were duplicated and the average of the results was used to analyze as discussed below in detail.

Mixture Design

In Superpave mixture design, the initial trial asphalt binder content for gradation A, B, and C was selected to be 4.5% based on the past experiences [20]. Three specimens were prepared for each blend, and prior to compaction by SGC, the loose mixtures were oven aged for 4hrs at 135˚C. Table 3 summarized the volumetric results of the tested specimens at the estimated asphalt content to achieve 4% air voids. Then the estimated properties of three mixtures were compared against the Superpave criteria. Results showed that gradation A and B were not acceptable based on a failure of the resulting mixtures to meet the criteria of dust proportion. Only gradation C can satisfy all specification limits and was finally selected as the design aggregate structure.

Following this, the mixtures with gradation C were evaluated at five asphalt contents at an interval of 0.5% centered at the estimated asphalt content to determine the optimal asphalt content. As a result, 5.0% was recommended as OAC to result in 4% air voids at N_{des}. All mixture properties were shown in Table 4. Furthermore, the specified medium gradation mixture currently used in airfield was designed by Marshall method. The volumetric properties were also illustrated in Table 4.

It can be seen from Table 4 that the Superpave mixture had higher air void and relatively lower asphalt content when compared with the Marshall mixture. To some extent, this was attributed to the difference between the Japanese specification and Superpave criteria. The Japanese specification had a higher requirement of VFA (voids filled with asphalt) over Superpave criteria, which could lead to higher OAC and lower air voids and consequently made the mixture very sensitive to rutting. Therefore, it was speculated that the higher requirement of VFA might be one of the possible reasons to account for the severe rutting in the heavy-duty loading condition.

Rutting Resistance - Wheel Tracking Test

As shown in Fig. 6, the two mixtures behaved very differently in the rutting test. The Superpave mixture showed a significantly lower rutting than the control Marshall mixture. This was consistent with the results from an earlier study [20]. After one hour, the rutting of the Marshall specimen was about 2 times higher than that of the Superpave specimen. This was mainly contributed by the coarse aggregate structure and lower OAC, which led to Superpave mixture to be more rutting resistant. Therefore, Superpave mixture was more attractable for situations where rutting performance was a priority. It was promising for use in the study airport to alleviate rutting.

Raveling Resistance - Steered Wheel Tracking Test

The results from steered wheel tracking tests were shown in Fig. 7. Superpave mixture showed a greater raveling resistance than the Marshall mixture. Again, this could be attributed to the excellent aggregate structure as well as relatively small amount of fine aggregate and mineral filler in the Superpave mixture.

Fatigue Cracking Resistance - Repeated Four Point Bending Test

Flexural fatigue test results were presented in Fig. 8. The Marshall specimen gave a longer fatigue cycle than the Superpave specimen mostly due to the higher asphalt content in Marshall mixture. But the fatigue performance of the Superpave mixture was considered acceptable because the difference between the two mixtures seemed insignificant. This could be explained because Superpave had an

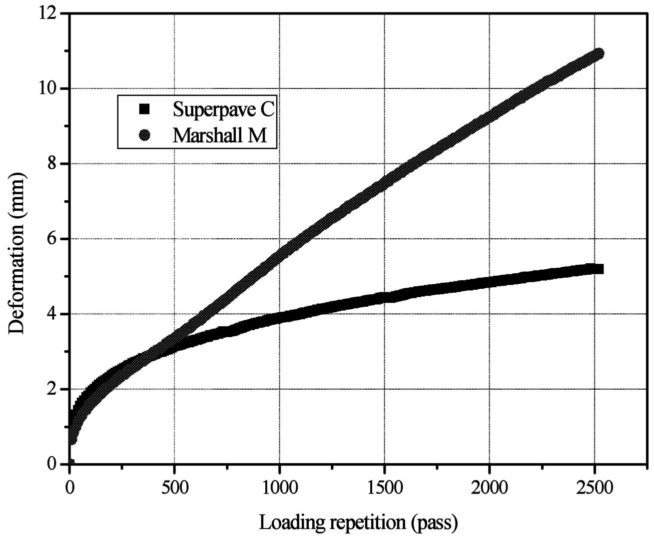

Fig. 6. Results of Wheel Tracking Test.

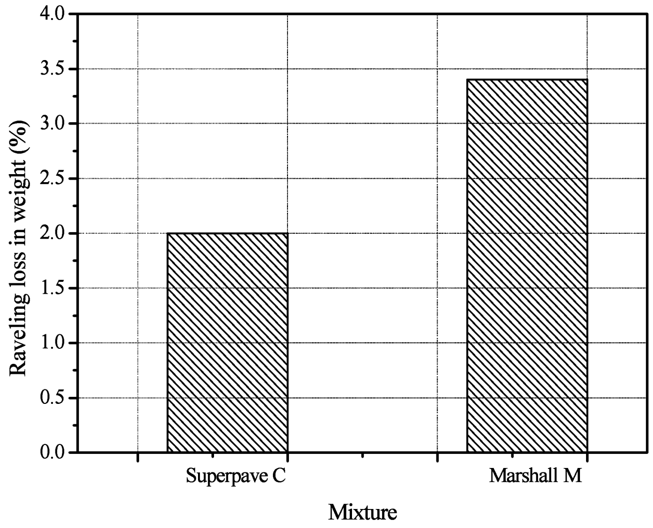

Fig.7. Results of Steered Wheel Tracking Test.

improved aggregate structure and a comparable dust to asphalt cement ratio though its asphalt content was relatively lower when compared with the Marshall mixture.

Thermal Cacking Resistance - Static Three Point Bending Test

Fig. 9 presented the results of strain at failure from three point bending tests. The Superpave specimens showed nearly similar strain at failure at low temperature with the Marshall specimen. This resulted in the conclusion that the Superpave mixture could achieve the similar thermal cracking resistance as the Marshall mixture.

Moisture Resistance - Indirect Tensile Strength Test

The results from indirect strength test were summarized in Fig. 10. The results obtained indicated that Superpave mixture showed a superior moisture resistance with the ITS ratio being 8% more than Marshall mixture. The reason was attributed perhaps to its improved

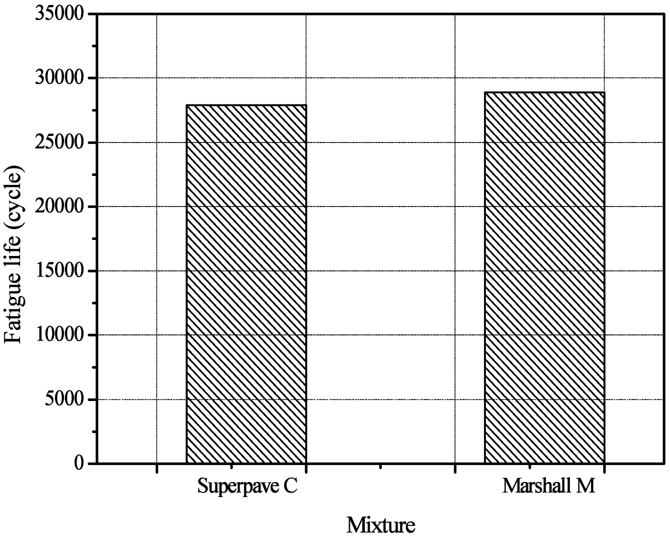

Fig. 8. Results of Fatigue Bending Test.

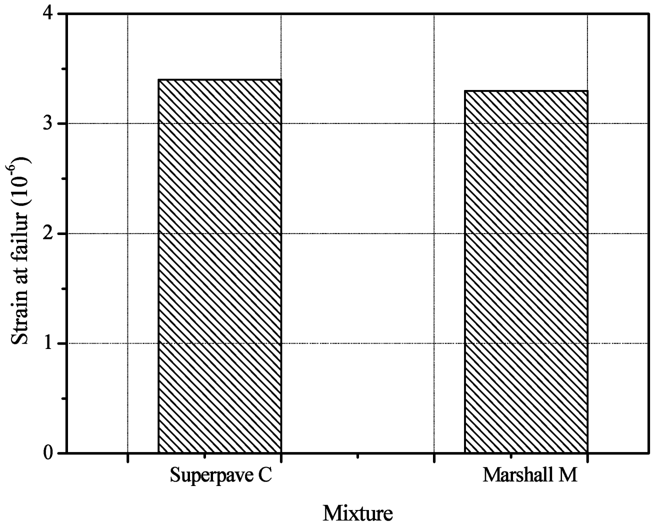

Fig. 9. Results of Static Bending Tests.

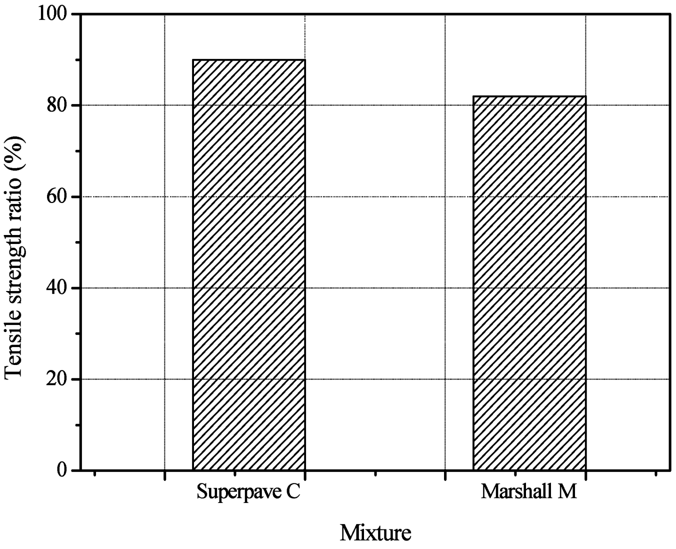

Fig. 10. Results of Tensile Strength Ratio.

aggregate structure and high compaction effort.

Summary and Conclusions

Based on the test results and following analysis on the engineering properties of HMA mixture designed by Superpave concept compared with the control Marshall mixture, the conclusions from this study were summarized as follows:

1. As the first study attempting to use Superpave in airfield in Japan, a very encouraging result was obtained that the selected coarse Superpave mixture below the restricted zone showed a significantly superior rutting resistance compared with the traditionally used Marshall mixture with the medium gradation. It was desirable for situations where rutting was a major concern.
2. The Superpave mixture exhibited similar or higher performances in terms of resistance to fatigue, thermal cracking, and moisture damage compared with the Marshall mixture.
3. Overall, to use Superpave concept to design HMA mixture was very promising for airport pavement judging from its excellent performance. It was expected that the selected coarse Superpave mixture could mitigate the rutting prevalent in recent years in the study airport.
4. Further research was recommended to construct the experimental pavement to verify the laboratory test results, and specify a more appropriate N_{des} from the economical and engineering point.

Disclaimer

The contents of this paper only reflect the views from the authors and do not necessarily reflect any official view.

References

1. Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D.Y., and Kennedy, T.W., (1996). Chapter 4: Hot Mix Asphalt Mixture Design Methodology, *Hot Mix Asphalt Materials, Mixture Design and Construction*, *Second Edition*, NAPA Research and Education Foundation, Lanham, Maryland, USA, pp. 173-181.
2. Proell, B.D. and Brown, E.R., (2007). Verification of the N Design Levels, *Journal of the Association of Asphalt Paving Technologists*, Vol. 76, pp.771-821.
3. Asphalt Institute, (2007). *The Asphalt Handbook (MS-4/7th Edition)*, Asphalt Institute Research Center, Lexington, KY, USA, pp. 198-201.
4. McGennis, R.B., Anderson, R.M., Kennedy, T.W., and Solaimanian, M., (1995). Background of Superpave Asphalt Mixture Design and Analysis, *Report No. FHWA-SA-95-003*, U.S. Department of Transportation, USA, pp. 16-28.
5. Hafez, I.H. and Witczak, M.W., (1995). Comparison of Marshall and Superpave Level I Mix Design for Asphalt Mixes, *Transportation Research Record*, No. 1492, pp. 161-165.
6. Habib, A., Hossian, M., Kaldate, R., and Fager, G.A., (1998). Comparison of Superpave and Marshall Mixtures for Low-Volume Roads and Shoulders, *Transportation Research Record*, No. 1609, pp. 44-50.
7. Swami, B.L., Mehta, Y.A., and Bose, S.A., (2004). Comparison of the Marshall and Superpave Design Procedure for Materials Sourced in India, *International Journal of Pavement Engineering*, 5(3), pp. 163 – 173.
8. Kavanagh, L.N., (2004). A 9-Year Evaluation of Field Cracking and Rutting Performance of SPS-9 Superpave Experiment, *Transportation Research Record*, No. 1896, pp. 138–146.
9. Sebaaly, P.E., Hand, A.J.T., McNamara, W.M., Weitzel, D., and Epps, J.A., (2004). Field and Laboratory Performance of Superpave Mixtures in Nevada, *Transportation Research Record*, No. 1891, pp. 76–84.
10. Sivaranjan S., (2005). Validation of Superpave Mixture Design and Analysis Procedures Using the NCAT Test Track, *Ph.D Dissertation*, Purdue University, West Lafayette, IN, USA.
11. Watson, D.E., Brown, E.R., and Moore, J., (2005). Comparison of Superpave and Marshall Mix Performance in Alabama, *Proceeding of 2005 Annual Meeting of Transportation Research Board*, TRB, National Research Council, Washington, D.C., USA, CD-ROM.
12. Ibrahim, M.A., (2007). Performance Evaluation of Superpave and Marshall Asphalt Mix Designs to Suite Jordan Climatic and Traffic Conditions, *Journal of Construction and Building Materials*, 21(8), pp. 1732-1740.
13. Sousa, J.B., Deacon, J.A., and Monismith, C.L., (1991). Effect of Laboratory Compaction Method on Permanent Deformation Characteristics of Asphalt Aggregate Mixtures, *Journal of the association of Asphalt Paving Technologists*, Vol. 60, pp. 533-585.
14. Ziauddin, A.K., Hamad, I.A.W., Ibrahim, A., and Rezqallah, R., (1998). Comparative Study of Asphalt Concrete Laboratory Compaction Methods to Simulate Field Compaction, *Journal of Construction and Building Materials*, 12(6), pp. 373-384.
15. Maupin, G.W., (1998). Comparison of Several Asphalt Design Methods, *Final report*, *VTRC 98-R15*, Virginia Transportation research Council, Charlottesville, Virginia, USA.
16. Robert, L., Peterson, K.C., Mahboub, R., Michael, A., Eyad, M., and Laith, T., (2003). Superpave® Laboratory Compaction versus Field Compaction, *Transportation Research Record*, No. 18321, pp. 201–209.
17. Airey, G.D., Collop, A.C., Zoorob, S.E., and Hunter, A.E., (2006). Comparison of Field and Laboratory Compacted Asphalt Mixtures, *Proceedings of the Tenth International Conference on the Structural Design of Asphalt Pavements*, Quebec City, Quebec, Canada.
18. John, D. and Mark, B., (2004). Superpave for Airfields, *Proceeding of 2004 FAA Worldwide Airport Technology Transfer Conference*, Atlantic City, New Jersey, USA, CD-ROM.
19. Cooley, L.A., Ahlrich, R.C., and Robert, S.J., (2007). Implementation of Superpave Mix Design for Airfield Pavements, *Proceeding of 2007 FAA Worldwide Airport Technology Transfer Conference*, Atlantic City, New Jersey, USA, CD-ROM.

20. Su, K. and Hachiya, Y., (2008). Evaluation of Superpave Mixture for Use in Heavy Duty Pavement in Airfield, *Journal of Japan Society of Civil Engineering*, 64(4), pp. 595-600.
21. Service Center of Port Engineering, (2007). *Specification for Civilian Airport Construction Works*, Tokyo, Japan, pp. 2.28-2.32, [In Japanese].
22. Sousa, J.B., Pais, J.C., Prates, M., Barros, R., Langlois, P., and Leclerc, A., (1998). Effect of Aggregate Gradation on Fatigue Life of Asphalt Concrete Mixes, *Transportation Research Record*, No. 1630, pp. 62-68.
23. Haddock, J., Pan, C., Feng, A., and White, T.D., (1999). Effect of Gradation on Asphalt Mixture Performance, *Transportation Research Record*, No. 1681, pp. 59-68.
24. Kandhal, P.S. and Mallick, R.B., (2001). Effect of Mix Gradation on Rutting Potential of Dense-Graded Asphalt Mixtures, *Transportation Research Record*, No. 1767, pp. 146-151.
25. Cominsky, R.J., Huber, G.A., Kennedy, T.W., and Anderson, R.M., (1994). The Superpave Mix Design Manual for New Construction and Overlays, *Report No. SHRP-A-407*, Strategic Highway Research Program, National Research Council, Washington D.C., USA.
26. Japan Road Association, (2007). *Test Manual for Pavement Materials*, Tokyo, Japan, Part. 3, pp. 57-62, [In Japanese].
27. Asphalt Institute, (2001). *Superpave Mix Design Series No. 2 (Sp-2)*. Asphalt Institute Research Center, Lexington, KY, USA.