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Article

Stability of Runway Grooving Under Repeated Large Aircraft Loads

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Abstract. On runway pavements in Japan, grooves for transverse directions should be set on most of runway area. The aim of runway grooving is to drain rain water on surface, which prevents from hydroplaning. According to the specification of Japan, two months as a "curing period" without a groove is necessary for sufficient durability of grooves after finishing a surface paving. This curing period is adopted regardless of amounts of loading and kinds of material. In particular, since the curing period is derived from the durability of HMA with straight asphalt binder, it might be possible to shorten the period by means of modified binder. And considering the trend of introduction of larger aircrafts, it is not always reasonable to set the curing period. In order to gain knowledge for setting curing period flexibly, the authors researched grooving stability in terms of the kinds of material in wheel tracking tests. The tests were conducted on three materials under the same tire pressure as that of the real aircraft (A-380). The three materials are two kinds of modified asphalt and straight asphalt. Then, full scale loading tests were conducted for the purpose of confirmation of results obtained from wheel tracking tests. As a result of the tests, the extent of grooving damage was improved by using modified asphalts compared to straight asphalt. In conclusion, to use advanced materials such as modified asphalts could achieve enough grooving stability even if larger aircrafts are served, and could shorten the curing period.

Keywords: Airport pavement, grooving, modified asphalt, wheel tracking test, full scale aircraft loading test.

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1. Introduction

On runway pavements in Japan, grooving is carried out over the full length of the runway in the longitudinal direction, and over 2/3 the width of the runway in the transverse direction [1]. Grooving is narrow width drainage grooves cut in the runway surface. When constructed with the normal shape, it has been confirmed that the drainage performance of the runway is maintained sufficiently and the skid resistance is improved [2]. In the specification of Japan [3], a minimum period of two months as a "curing period" without grooving is necessary for sufficient durability of grooving after finishing a surface paving. However, taking into consideration the types of asphalt materials, the high temperature sensitivity of asphalt, and 30-day curing period recommended by the Federal Aviation Administration [4], it is not necessarily reasonable to apply two months curing period uniformly to all airports in Japan. There have been many studies into the stability of grooving, focusing on materials and the environmental conditions used at the location of construction. Sato *et al.* [5] surveyed the basic properties of grooving damage and investigated runway surfacing materials and curing periods. They indicated that a minimum of two months curing is necessary before carrying out grooving. Hachiya *et al.* [6] and Wu *et al.* [7] investigated the stability of grooving on runway pavements, taking into consideration conditions such as asphalt type, recycled materials, particle size distribution of aggregates, traffic history, etc. They indicated measures to maintain the shape of the grooves of the grooving. However, these studies did not extend to investigating how the properties of the asphalt changed during the curing period. Also, there are many examples where the tire contact pressure was taken to be about 0.6MPa. Considering the trend of introduction of larger aircrafts such as the Airbus A380-800, it is not certain that the same conclusions can be obtained under high contact pressure conditions. In order to obtain fundamental knowledge for proposing a rational method of setting the curing period necessary prior to carrying out grooving, the authors carried out repeated loading tests with loads equivalent to large aircraft and determined the state of damage of the grooves. In these tests, the asphalt type, temperature of the pavement, and the number of days of curing were varied.

2. Investigation of Stability of Grooves Using Laboratory Tests

2.1. Test Method

The failure modes of grooving include clogging and edge defects. Of these defects, clogging of grooves is considered to greatly affect the drainage performance of runways, so the effect of load on clogging of grooves was focused on in this study. There are other causes that reduce the drainage performance, such as adhesion of aircraft tire rubber, but here clogging due to loading only is evaluated. To evaluate the clogging due to aircraft loads, repeated loading tests were carried out using the wheel tracking test machine shown in Fig. 1. This machine can apply loads equivalent to a large aircraft, and tests can be carried out at any temperature between 0 and 60°C. The test specimens used in the tests were produced based on "Method of Preparation of Test Specimens" for wheel tracking tests [8]. The grooving was carried out using a concrete cutter after outdoor exposure in the five exposure patterns: 0, 15, 30, 45, and 60 days. The shape of the groove is as shown in Fig. 2, a shape commonly used for airport pavements. The materials used in the test specimens were mixtures using straight asphalt 60/80, polymer modified asphalt type II (PMA II), and polymer modified asphalt type III (PMA III). Table 1 shows the quality standards prescribed for the PMA II and PMA III, and the property of these asphalts used in the tests. Also, wheel tracking tests were carried out on these asphalt mixtures, and dynamic stability was obtained for each material. The values of dynamic stability, the number of loadings to produce a 1mm rut in the asphalt mixture, were obtained at a test temperature of 60°C. The tests condition was set as described the reference [8] and the results are also shown in Table 1. Repeated loading tests were carried out at 20, 40, and 60°C, because the specimen temperature in the tests has a major effect on the deformation of asphalt mixtures. The contact pressure of the test wheel during loading was about 1.5MPa corresponding to a large aircraft such as the Airbus A380-800, based on the trends in the changes in forms of transport for passengers and cargo. The test wheel was controlled at a speed of 200mm/s to simulate the low travel speed at runway end. In the tests, the width and depth of the grooves were measured after 0, 20, 50, 100, 200, 500, 1000, 2000, and 5000 load repetitions on a test specimen. The test conditions are summarized in Table 2. The groove width and depth were measured using a laser displacement meter. The laser displacement meter was installed on a guide, and the guide was moved horizontally at the speed of 10mm/s measuring the displacement in the vertical direction. For each test specimen measurements were carried out on five measurement lines, and the groove widths and depths in the five measurement lines were averaged. The sampling frequency was 200Hz. Damage to the groove width and depth was evaluated as a percentage reduction. Here, the percentage reduction means the reduction in the amount of width and depth, and is defined by the following Eq. (1).

$$\ell = \frac{a - a'}{a} \times 100\,(\%) \tag{1}$$

ℓ : Percentage reduction of the groove width or depth, a : Width or depth of the groove before the test; a' : Width or depth of the groove after the test.

Fig. 1. Wheel tracking test machine.

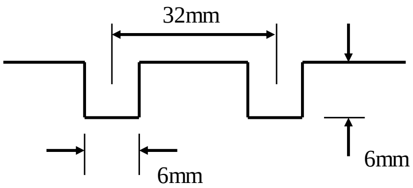


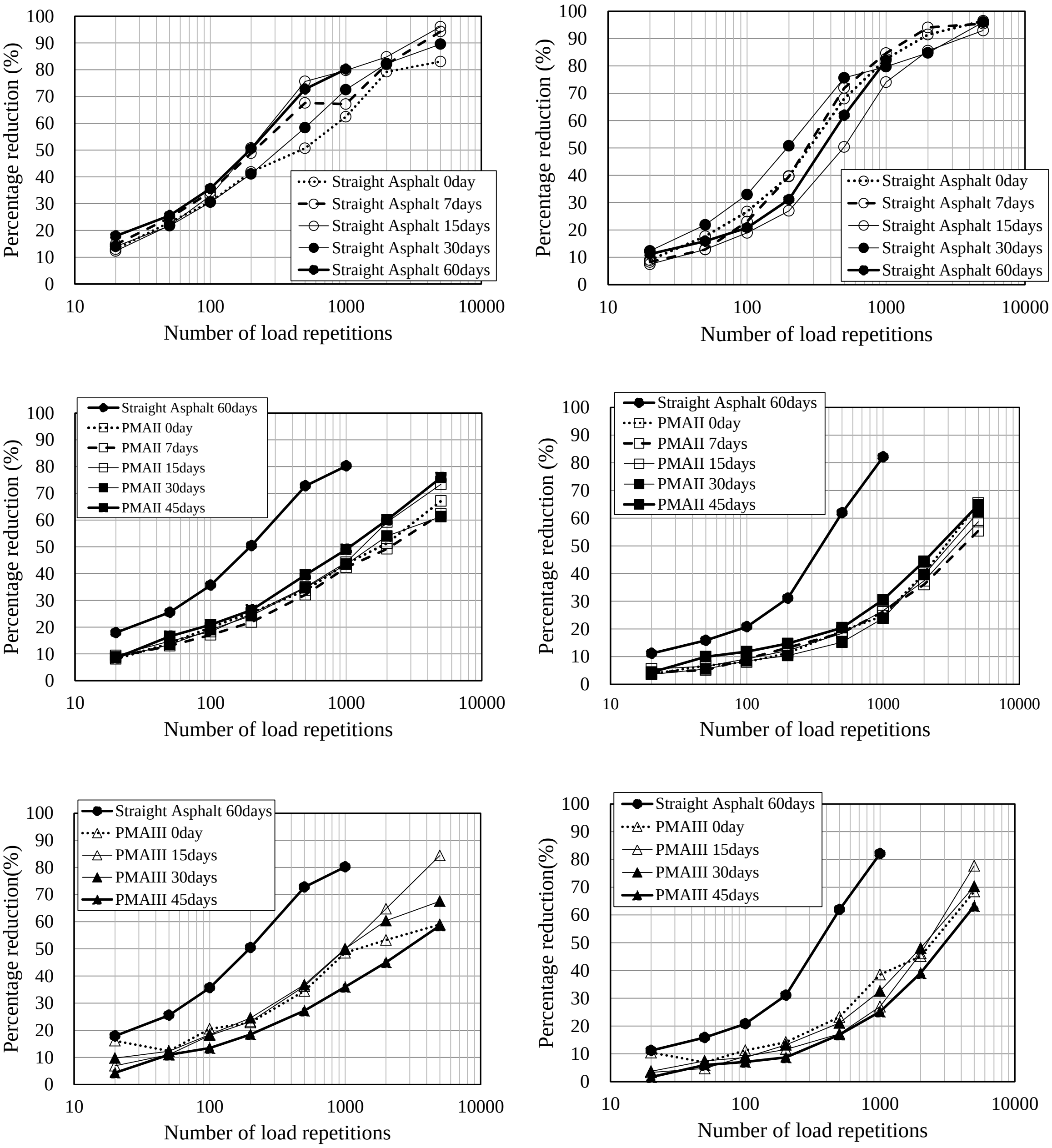
Fig. 2. The shape of the grooving.

Table 1. Quality standards and property of asphalts used in this study.

Index		Unit	Straight asphalt 60/80		PMA II		PMA III	
			Quality standard	Test value	Quality standard	Test value	Quality standard	Test value
Softening point (25°C)		°C	44.0 - 52.0	47.0	56.0 - 70.0	61.5	80.0 +	90.5
Ductility (15°C)		cm	100 +	100 +	30 +	100 +	50 +	93
Toughness (25°C)		N・m	-	-	7.8 +	19.6	20 +	27.4
Tenacity (25°C)		N・m	-	-	3.9 +	17.1	-	-
Penetration (25°C)		1/10mm	60 - 80	70.0	40 +	51	40 +	51
Mass change percentage after thin Film Oven Test		mass%	0.6 -	0.04	-	0.02	0.6 -	0.02
Remaining percentage of penetration after Thin Film Oven Test		%	58 +	70.1	65 +	91.0	65 +	97.8
Flash point		°C	260 +	364	260 +	335	260 +	337
Density		g/cm^3	1.000 +	1.033	-	1.030	-	1.028
Kinematic Viscosity	120°C	mm^2/s	-	944	-	-	-	-
	150°C		-	213	-	-	-	-
	180°C		-	71.1	-	-	-	-
Recommended temperature in making specimens for laboratory test	Mixing temperature	°C	-	150 - 156	-	170 - 180	-	175 - 185
	Compacting temperature	°C	-	139 - 143	-	155 - 165	-	165 - 175
Dynamic stability (60°C)		mm/pass	-	326	-	8034	-	7740

Table 2. Test conditions.

Material	Curing Period (Days)						Temperature (°C)	Contact Tire Pressure (Mpa)	Traveling Speed (mm/s)
	0	7	15	30	45	60			
Straight Asphalt 60/80	O	O	O	O	-	O	20,40,60	1.5	200
PMA II	O	O	O	O	O	-			
PMA III	O	-	O	O	O	-			



(a) Width (b) Depth

Fig. 3. Percentage reduction of the grooves for the number of days of curing.

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2.2. Test Results

Figure 3 shows the relationship between the number of load repetitions and the groove percentage reduction for each number of days of curing. Figure 3(a) and 3(b) show the percentage reduction of the groove width and depth. In the figure, the test temperature was 40°C, and the results are shown for asphalt mixtures using straight asphalt, PMA II, and PMA III. The groove percentage reduction is the average for three test specimens. From these figures it can be seen that for each asphalt mixture, there is no significant difference in the groove percentage reduction with the number of days of curing. In past studies, tests were carried out using the design loads for roads in Japan. Many of them suggested that there was an asphalt stability improvement effect by providing the number of days of curing. However, from the above test results, the effect of curing is relatively small when the loading is severe. There is a possibility that sufficient stability improvement effect will not be obtained. Figure 4 shows the relationship between the number of load repetitions and the groove percentage reduction for test temperatures of 20°C, 40°C, and 60°C. Test specimens used in the tests were cured for 15 days. When the loading tests were carried out at 20°C, there was only a small difference due to the three different types of asphalt mixtures in the initial stage of loading. On the other hand, when the tests were carried out at 40°C and 60°C, which are near or above the temperature for softening point of straight asphalt (47.0°C), it was found that the groove damage for the asphalt mixtures using straight asphalt was significantly larger compared with the asphalt mixtures using modified asphalt. This indicates that when the pavement temperature is high, the groove damage can be reduced by using modified asphalt. Comparing the groove damage for asphalt mixtures using PMA II and PMA III, there was no difference in percentage reduction, regardless of test temperature.

On the basis of these results, the effect of materials and curing period on the percentage reduction can be evaluated. If the results for the asphalt mixtures using straight asphalt with 60 days of curing as indicated by the specification in Japan are considered to be the present limiting value of clogging, it can be seen that the effect of using high dynamic stability materials such as polymer modified asphalt, is greater than the effect of curing. Also, the values from the results for the asphalt mixtures using modified asphalts, whose curing periods are range from 0 day to 45 days, are lower than the present limiting values of clogging. So, these results suggest that required curing period could be shorten by using asphalt materials with high dynamic stability.

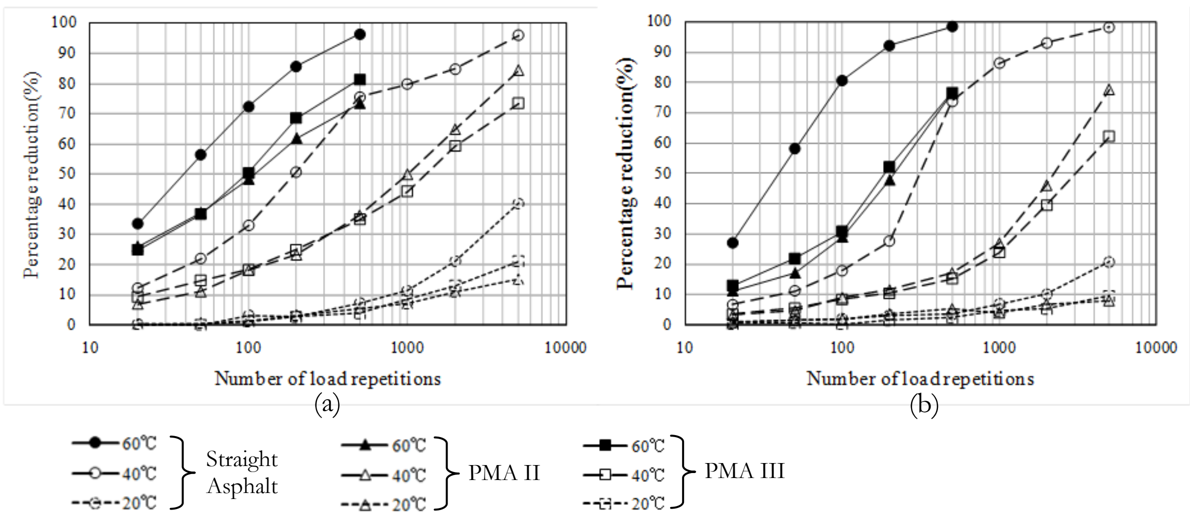


Fig. 4. Percentage reduction of the grooves for test temperatures.

3. Full-Scale Wheel Repeated Loading Tests

3.1. Test Method

In order to confirm the test results in laboratory in the field, repeated loading tests were carried out using full-scale wheels in an outdoor test field. This test was not carried out to evaluate the curing effect, but to evaluate the impact of materials and load temperature on the test results. The tests were carried out during the winter (middle of February) and the summer (beginning of September) to take into account the effect of pavement temperature. The temperature conditions in the tests are shown in Table 3. Figure 5 shows a cross-section of the pavement used in the tests. A binder course and a surface course were constructed on an existing asphalt pavement. Asphalt mixtures using straight asphalt 60/80, PMA II, and PMA III were used in the surface course, the same as for the laboratory tests. In the laboratory tests, there was no difference between the amount of groove damage for the asphalt mixtures using PMA II and PMA III. So, in the outdoor tests, tests for the asphalt mixtures using PMA III were carried out only during the winter. The grooving was carried out over a 3.0m area in the surface course of each asphalt mixture. The grooves were a shape commonly used in airport pavements as shown in Fig. 2. The prototype traveling load vehicle shown in Fig. 6 was used in the full-scale wheel repeated loading tests. The vehicle was a loading device that simulated one set of wheels of an aircraft, pulled by a trailer, with ingots loaded on the top of the loading device to adjust the axle loads. In these tests the axle load was adjusted to obtain a contact pressure of 1.5MPa equivalent to a large aircraft such as the Airbus A380-800. Also, the target wheel traveling speed was about 7.5km/h, taking into consideration the trailer performance and safety during the tests. Figure 7 shows the full-scale wheel loading at the surface with grooving. The maximum number of load repetition was 720, and the groove damage was evaluated from the percentage reduction of the groove at 0, 30, 60, 120, 240, 360, 480 and 720 load repetitions. The definition of the percentage reduction was the same as for the laboratory tests. The groove width and depth were measured using a laser displacement meter. Also, since the asphalt mixtures significantly chipped off during loading, "the scattered asphalt mixtures" were collected over a length of 3.0m and width 1.9m in the areas where the grooves were cut, and its mass was measured. For measurement of the groove width and depth, six positions were selected in an area 30×30cm from the loading wheel traveling position, and five measurement lines were set up in each of these areas. The average groove width and depth on these five measurement lines was obtained, and the results for the six areas were averaged.

Table 3. Temperature conditions.

Season		Winter	Summer
Air temperature	Ave (ºC)	4.7	28.2
	Max (ºC)	6.1	30.5
	Min (ºC)	1.9	25.4
Surface temperature of pavement	Ave (ºC)	9.3	41.0
	Max (ºC)	23.3	58.5
	Min (ºC)	0.7	24.9
Boundary temperature between surface course and binder course	Ave (ºC)	8.5	39.7
	Max (ºC)	15.7	51.2
	Min (ºC)	4.5	29.0

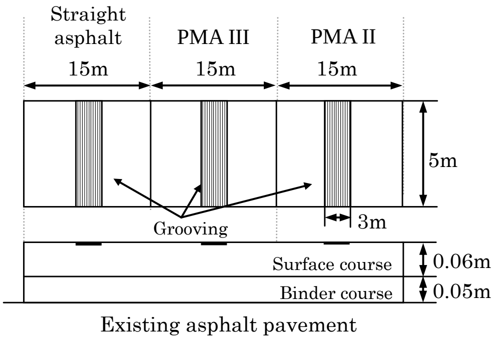


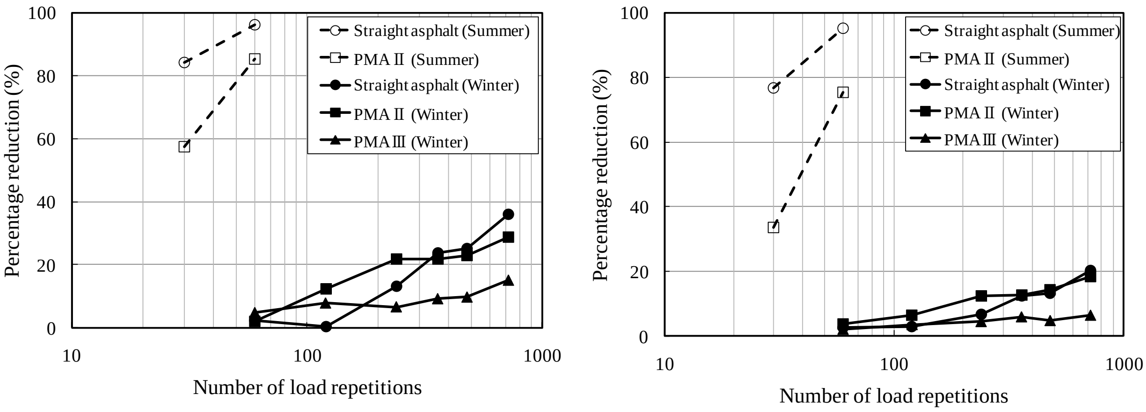
Fig. 5. Cross-section of the pavement.

Fig. 6. Prototype traveling load vehicle.

Fig. 7. Full-scale wheel loading at the surface with grooving.

3.2. Test Results

Figure 8 shows the relationship between the number of load repetitions and the groove percentage reduction. Looking at the results for winter and summer, there is a distinct effect of test temperature. In the winter test results, the amount of groove damage was small for all the asphalt mixtures used. There was little difference between the groove percentage reduction for the asphalt mixtures using straight asphalt and PMA II. On the other hand, the groove damage was reduced by using asphalt mixtures that use PMA III. In the summer test results, there were significant changes in the groove. The groove percentage reduction for the asphalt mixtures using PMA II was significantly smaller compared with the asphalt mixtures using straight asphalt. From the above, even when the loads are equivalent to those of large aircraft, it can be concluded that it is possible to reduce the actual groove damage on site by using asphalt mixtures that use modified asphalt compared with the case where asphalt mixtures using straight asphalt.



(a) Width (b) Depth

Fig. 8. Percentage reduction of the grooves.

The failure modes also changed with temperature. Figure 9 shows the results for measurement of the quantity of scattered asphalt mixture. In the winter tests, the quantity of scattered asphalt mixture was greatest in the order straight asphalt, PMA III, and PMA II. Many fragments were seen in all the asphalt mixtures in the initial loading stage. Especially, fine fragments were seen only in the straight asphalt mixture. As the number of load repetitions increased, larger particle size fragments were found in all the asphalt mixtures. In the summer tests, the quantity of scattered material was significantly larger for straight asphalt. This result is the same trend as in the winter tests. Relatively large particle size fragments were found in all the asphalt mixtures from the initial loading stage. Figure 10 shows the observed failure mode of asphalts. In the winter tests, the temperature near the pavement surface was around 10°C, so the asphalt viscosity effect was considered to be small. In the case of modified asphalt, the resistance to the load was high, so the squeezed asphalt was not pulverized (Fig. 10(a)). On the other hand, for the straight asphalt, the squeezed asphalt was pulverized by the loading (Fig. 10(a)), so the fine fragments were produced. In this case, with this measurement system for measuring the width and depth, the width were found to be greater for the straight asphalt compared with the modified asphalt, because the squeezed asphalt was pulverized. This can explain the results for the groove percentage reduction shown in Fig. 9. In the summer tests, the protruding parts of the groove were crushed in a mode that resembled compressive failure of short column in all the asphalt mixtures (Fig. 10(b)). It seems that this failure mode was observed when the pavement temperature is high. These observations were made from the results of groove deformation in the laboratory tests and the in-situ tests. In the future it is necessary to study the failure mechanisms and their effect on the traveling safety of aircraft.

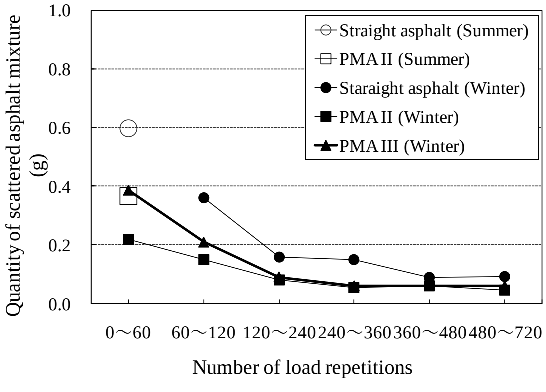


Fig. 9. Quantity of scattered asphalt mixture.

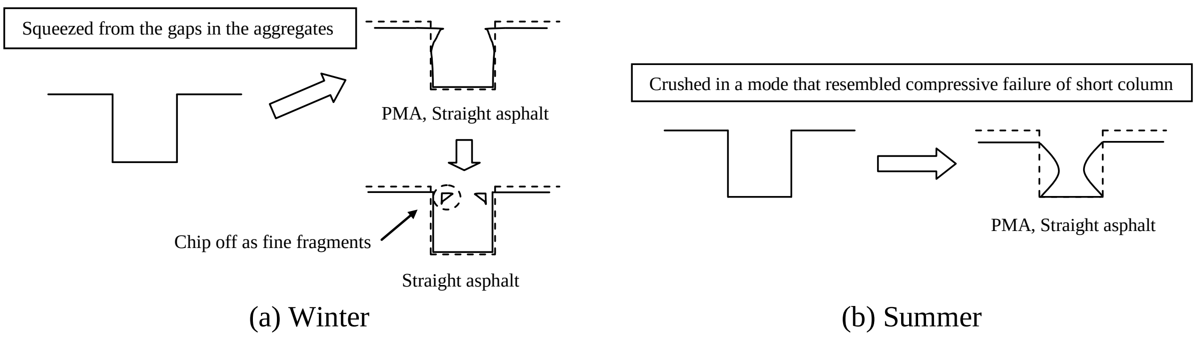


Fig. 10. Failure mode of asphalt mixture.

4. Conclusions

In this study, laboratory-scale repeated loading tests and full-scale repeated loading tests were carried out on asphalt mixtures using straight asphalt and modified asphalt with contact pressure (1.5MPa) equivalent to a large aircraft, and the groove damage was measured. From the results, the following was concluded.

(a) When the contact pressure is large the effect of curing is small, so there is a possibility that sufficient groove stability improvement effect will not be obtained from curing.

(b) When the contact pressure is large the effect of materials or temperature has a greater impact on groove stability than the effect of curing, and if high dynamic stability materials are used, the effect of improved groove stability can be obtained.

(c) The groove failure mode can change depending on the temperature and the materials used. Therefore it is necessary to investigate in the future the effect of each on the failure mechanisms and the traveling safety of aircraft.

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