Development and Effect of Pavement Material that Combines Two Functions

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ABSTRACT: Pavement technology that contributes to environmental improvement, classifies the application field into earth environment, city environment, or road space environment, and the practical use of individual technology has been developed. We have separately developed and since 1997 have been putting into practical use a kind of pavement material that can restrain the rise of a road surface temperature in the summer by evaporation of moisture absorbed into the material and which can also restrain the freezing of the road surface in winter, by adding in a super absorbent polymer (which is used for greening of deserts) into the pavement material that causes salt and moisture to be absorbed. In recent rears, however, summertime temperatures in the heavy snowfall areas have been on the rise, and vehicular traffic in the traditionally warmer regions has come to be paralyzed by snowfall in the winter months. And these factors have prompted us to start thinking about the possibility of developing a pavement using super absorbent polymer that combines both of these functions. This paper reports on the development and effects of a pavement material that has the two useful functions of restraining freezing in winter and restraining rising temperature in summer in the same pavement.

KEY WORDS: Anti-freezing pavement, water-retentive pavement, super absorbent polymer.

1. INTRODUCTION

Practical application of the pavement technologies contributing to environmental improvement has been pursued individually according to their intended spheres of application, namely, global, urban, and roadside/road space environments.

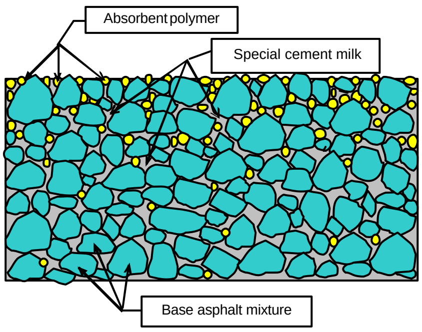


Fig. 1: Outline sectional drawing of FAP and Cool Pave

Our company developed and commercialized the effect-restoration type anti-freezing pavement that prevents road surface from being frozen in the winter time (hereinafter "FAP [Freeze Attack Pave]") and the water-retentive pavement that curbs the rise in the road surface temperature in the summer time (hereinafter "Cool Pave") at different times during the period from 1997 to 1998 by using the technique of incorporating absorbent polymer into the pavement to absorb and retain salts and water as illustrated in Fig. 1.(Those shows references, Cool Pave is *"Development and Practical Use of Moisture Retaining Pavement (MRP)"* and FAP is **"***Functional Recoverable Freeze-Preventing*

Pavement")

Both FAP and Cool Pave can reduce the environmental loads in that the former requires spraying of anti-freezing agents such as calcium chloride and sodium chloride less frequently than the similar techniques, and the latter is expected to curb the atmospheric temperature around the roadside due to its effect to reduce the road surface temperature in summer season. Recently, however, the snowy cold-climate regions need to take anti-warming measures in summer , and the traffic paralysis caused by infrequent snowfalls in winter is a newly-emerged problem in the warm-climate regions. To meet such needs, therefore, we have worked on the development of "all-season type environmentally-friendly pavement" that can serve both as an anti-warming measure in summer and as an anti-freezing measure in winter. The following is the results of our efforts to improve our technologies based on construction tests.

2. DIRECTION OF DEVELOPMENT

We considered it more feasible to focus on urban areas as the target environment and add anti-freezing and cold resistance functions to the existing water-retentive pavement (Cool Pave), which already had a function to reduce the road surface temperature, rather than to add a water-retention function to the pavement for slopes and bridges in mountainous regions, for which the anti-freezing function is the first priority, with a view to enhancing its capabilities to reduce the environmental loads. The development efforts were made in that direction.

3. EVALUATION OF NEW CEMENT MILK FOR PENETRATION

Based on the study on the existing technologies and the direction of development mentioned above, the materials of the new cement milk for penetration were selected by taking the following points into consideration. Then, the performance of the four types of cement milk were tested.

1)Materials having highly water-retentive quality due to capillary phenomenon were selected as the solidification materials for the cement milk for penetration (solidification materials "C" and "D").

2)Instead of PNVA (poly-N-vinylacetoamide), which was used for FAP, polyethylene oxide was selected as the absorbent polymer as it had proved its performance in Cool Pave and had excellent gelation stability (absorbent polymer "B"). The mix formulas of the four types of new cement milk are shown in Table 1.

Table 1: Mix formulas of the new cement milk for penetration

	Type of cement milk		Solidification material	Water	Absorbent polymer	Anti-freezing agent	Others (external additive)	Total
Existing technique	FAP	Material name	Solidification material "A"	Tap water	Absorbent polymer "A"	KAC	Black pigment	
		Mix proportion (%)	65.3	31	0.4	3.3	-3.3	100
	Cool Pave	Material name	Solidification material "B"	Tap water	Absorbent polymer "B"	—	—	
		Mix proportion (%)	47.7	51.8	0.5	—	—	100
New cement milk for penetration	Mixture "1"	Material name	Solidification material "C"	Tap water	Absorbent polymer "B"	KAC	—	
		Mix proportion (%)	52.4	42.8	0.4	4.4	—	100
	Mixture "2"	Material name	Solidification material "D"	Tap water	Absorbent polymer "B"	KAC	—	
		Mix proportion (%)	47	48.6	0.4	4	—	100
	Mixture "3"	Material name	Solidification material "C"	Tap water	Absorbent polymer "B"	—	—	
		Mix proportion (%)	56.8	42.7	0.5	—	—	100
	Mixture "4"	Material name	Solidification material "D"	Tap water	Absorbent polymer "B"	—	—	
		Mix proportion (%)	51.1	48.5	0.4	—	—	100

3.1 Results of Performance Evaluation Tests

To evaluate the performance of each type of new cement milk for penetration, test pieces were prepared by producing base asphalt mixture (polymer-modified asphalt type-H was used: 300 × 300 × 50 mm) that contained 18% of continuous air voids and injecting each type of cement milk so that it fully penetrated the asphalt mixture.

3.1.1 Reduction in Road Surface Temperature

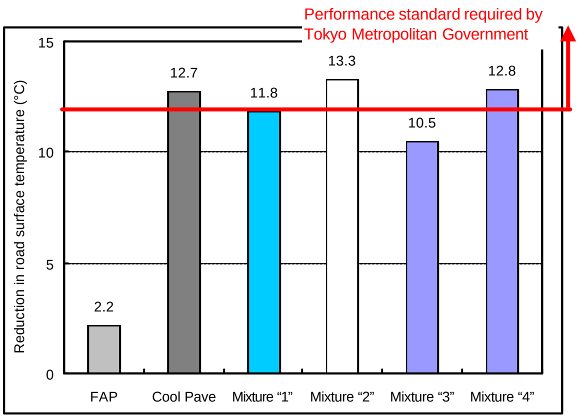


Fig. 2: Results of indoor irradiation test for each pavement material

After soaked in water of 20°C for 24 hours, each pavement material underwent indoor irradiation test (in accordance with the "Separate Volume"of"Pavement Performance Evaluation Method") to measure the reduction in surface temperature as compared with dense graded asphalt mixture as control.

Fig. 2 shows the results of the test. Tokyo Metropolitan Government requires that water-retentive pavement fully penetrated with water-retentive material should reduce the surface temperature by 12°C or more as against the control surface, and Cool Pave and Mix formulas "2" and "4" met this requirement.Therefore, it was found that Mix formulas "2" and "4"have sufficient performance as water-retentive pavement.

3.1.2 Adfreezing Strength of Ice to Pavement Materials

After an amount of 30% solution of calcium chloride equivalent to 0.3 L/m^2 (equivalent to 90 g/m^2) was sprayed once on the surface of the pavement materials, the adfreezing strength test (-5°C: in accordance with the "Separate Volume" of "Pavement Performance Evaluation

Method") was conducted repeatedly. The test results are shown in Fig. 3. Ice adfreezing to a pavement material having lower adfreezing strength is easier to come off, which means that such material has greater anti-freezing effect. According to the test results, all the pavement materials tended to show increase in adfreezing strength as the test was repeated, due to the fact that the concentration of the calcium chloride solution sprayed on them before the first test decreased with each trial. Though the adfreezing strength of Mix formulas "2", "3" and "4" increased by approximately 0.2 MPa with each test from the first to the fifth, they showed lower adfreezing strengths as compared with that of the dense graded asphalt mixture control at all tests, and their adfreezing strengths finally became lower than the control by approximately 30% at the sixth test. It was confirmed that they make it easier for the ice adfreezing to them to come off as compared with dense graded asphalt mixture.

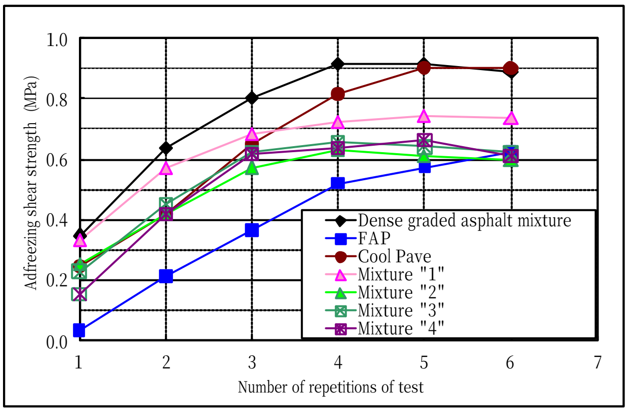


Fig. 3: Results of adfreezing strength test for each pavement material

3.1.3 Residual Salt Concentration

The anti-freezing effect of salts becomes greater as their concentration becomes higher, and it is expected that lower adfreezing strength is associated with higher salt concentration. To confirm this, residual salt concentration was measured.

After an amount of 30% solution of calcium chloride equivalent to 0.3 L/m^2 was sprayed once on the surface of the test piece for each mix formula, 5 cc of water was sprayed on the 10 × 10 cm space on the surface repeatedly at 15-minute intervals, and the salt concentration (in NaCl equivalent) was measured. Fig. 4 shows the results of the test. According to the test results, the dense graded asphalt mixture showed the highest residual salt concentration of 9.5% at the first test, but the concentration became 0% at the fourth test. In contrast, the residual salt concentration of Cool Pave and FAP became 0% at the 15th and 20th test, respectively, and Mix formulas "1", "2", "3" and "4" showed residual salt concentrations of higher than 0% even at the 21st test. From the in-situ data of FAP, it was revealed that anti-freezing effect appeared at -5°C only if the salt concentration was 1.2% or higher, and this concentration level was adopted as our in-house standard. Before the salt concentration had decreased to that level, dense graded asphalt mixture, Cool Pave, and FAP and Mix formulas "1" and "3" required 1 to 2, 4 to 7, and 3 to 7 test repetitions, respectively, whereas Mix formulas "2" and "4" required 3 to 10 repetitions. As a result, it is assumed that Mix formulas "2" and "4" has relatively greater anti-freezing effect.

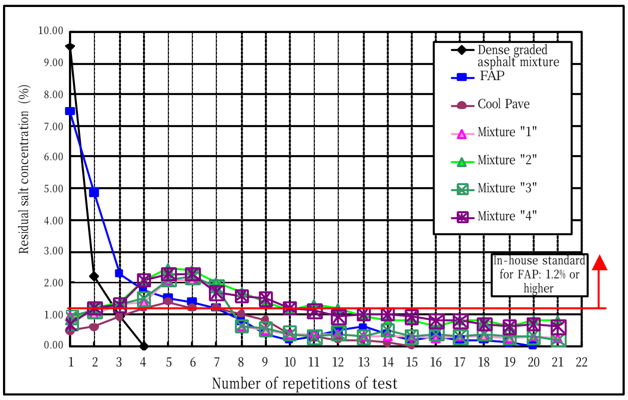


Fig. 4: Results of residual salt concentration test for each pavement material

Furthermore, what was distinctive of Cool Pave and Mix formulas "1" to "4", which were prepared with water-retentive quality as the main focus, was that their residual salt concentrations were on the increase up until the 5th test, whereas those of dense graded asphalt mixture and FAP gradually decreased each time water was sprayed on them. This occurs presumably because the residual salt concentration around the surface of the test piece decreases temporarily at the outset of the test due to the penetration of the calcium chloride solution into its inside, but increases gradually by spraying water repeatedly as the salts ascend to the surface to keep the ions at equilibrium.

3.1.4 Durability after Repetitive Freeze-Thaw Cycles

Four core samples (ϕ = 10 cm) were collected from each test piece (300 × 300 × 50 mm), and they were subjected to 150 freeze-thaw cycles (simulating use on actual road in three seasons) at temperatures between -20°C and +10°C. After that, low-temperature Cantabro test (-20°C) was conducted to evaluate the rate of aggregate loss. Porous asphalt mixture which was not penetrated with cement milk (containing 18% of continuous voids, and using polymer-modified asphalt type-H) was used as control, and underwent the same test. The test results are shown in Fig. 5. Based on the seven-year follow-up study and other data, the in-house standard for FAP requires that the rate of aggregate loss should be 20% or less. Only Mix formula "2" met this requirement. Mix formulas "2" and "4" use the same absorbent polymer ("B") and solidification material ("D"), and can be considered basically identical though they differ in use of anti-freezing agent (KAC: potassium acetate) and amount of water mixed. It is presumed that the higher rate of aggregate loss shown by Mix formula "4" was caused by disuse of KAC, which facilitated gelation of absorbent polymer to increase the flow value, thus interfering with the penetration of cement milk. Cement milk is known to reduce the aggregate loss by serving as a reinforcing material after it has become hardened. This presumption is also supported by the fact that the rates of aggregate loss of Mix formulas "1" to "4", which was penetrated with cement milk for penetration, were all lower than that of the porous asphalt mixture, which was approximately 40%.

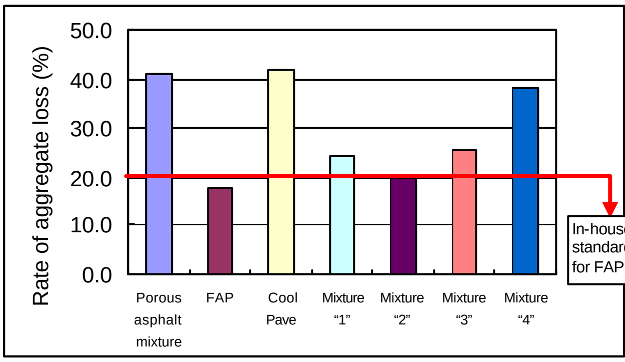


Fig. 5: Results of low-temperature Cantabro test after freeze-thaw cycles for each pavement material

3.2 Conclusion on Evaluation of New Cement Milk for Penetration

According to the results of the indoor tests mentioned above, which evaluated the pavement materials penetrated with new types of cement milk, Mix formulas "2" and "4" excelled in water-retentive quality.

With respect to anti-freezing effect of pavement, Mix formula "2" achieved the best results, followed by Mix formula "4". We concluded that Mix formulas "2" and "4" achieved the results we had intended, being excellent in both water-retentive quality and anti-freezing effect. Therefore, we named them "Vironment Pave", and examined them further in in-situ situations.

4. IMPLEMENTATION OF IN-SITU TEST CONSTRUCTION

Based on the results of the indoor evaluation tests, test construction of pavement using Mix formula “2” and “4”, which achieved excellent results, was implemented in Fukui Prefecture on January 29, 2007 (pavement area: approximately 80 $m^2 \times 2$, width: 4 m, length: 20 m, t = 5 cm, control pavement section: existing dense graded asphalt pavement).

4.1 Examination of Effects

4.1.1 Anti-Freezing Effect in Winter

As the test construction site had snowfall from January 17, 2008, and the temperatures dropped below freezing, we conducted in-situ investigation to find the following.

1) On January 17, the surface temperature of the dense graded asphalt pavement around Vironment Pave was 4°C as measured at 1:40 pm, whereas the surface temperature of Vironment Pave was 0°C. The snow on the dense graded asphalt pavement surface was melting while the snow on Vironment Pave was yet to thaw.

2) However, close observation of Vironment Pave surface revealed that the snow on the spots where core samples were collected was particularly slow to melt, and those spots were iced. This was because the holes left after core sampling were filled by injecting conventional cement mortar instead of the cement milk for Vironment Pave. Only those spots froze, and Vironment Pave surface did not freeze though snow remained unmelted. From this observation, it was confirmed that the cement milk for Vironment Pave had anti-freezing effect (see Photo 1).

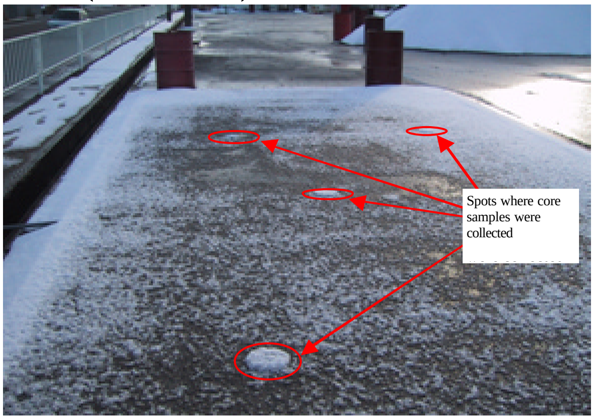


Photo 1:Condition of spots where core samples were collected

Photo 2: Condition of pavement after snow was removed

3) On the early morning of January 18 (6:40), with the atmospheric temperature below -1.5°C (road surface temperatures of both dense graded asphalt pavement and Vironment Pave were -2.0°C), the dense graded asphalt pavement was frozen, whereas Vironment Pave surface was not frozen though snow remained on it, and the snow could be removed with ease (see Photo 2). In contrast, the ice that stuck to the dense graded asphalt pavement surface in the control pavement section could not be removed by any means. From this finding, it was confirmed that Vironment Pave had anti-freezing effect. It was also found that the residual salt concentration (in NaCl equivalent) was considerably low at 0.2 to 0.4%.

4.1.2 Summary of Investigation Results in Winter

The investigation conducted in winter revealed the following:

1) From the results of the in-situ investigation, it was found that Vironment Pave showed anti-freezing effect when the atmospheric temperature was below -1.5°C. It was confirmed that the anti-freezing effect appeared if residual salt concentration (in NaCl equivalent) on the pavement surface was at least 0.3%.

2) As the surface of Vironment Pave is colored white, it absorbs less heat when exposed to direct sunlight as compared with the conventional dense graded asphalt pavement. Thus, it is likely that the snow on Vironment Pave is slow to start melting.

5. IMPROVEMENTS OF DELAY IN SNOW-MELTING

In order to improve the delay in snow-melting as mentioned above, black pigment was added to the solidification material for Vironment Pave to the extent that it does not impair the temperature-reduction effect in summer.

An amount of black pigment corresponding to 0.5 to 5.0% of the solidification material was added to it, and indoor irradiation test (in accordance with the "Separate Volume" of "Pavement Performance Evaluation Method") was conducted. It was found that when certain amount of black pigment was added, reduction in surface temperature by 12°C or more as against dense graded asphalt pavement (performance standard adopted by Tokyo Metropolitan Government) was achieved.

Sliced ice of 1 cm thickness was laid over the surfaces of Vironment Pave added with such amount of black pigment and dense graded asphalt pavement, and they were left under the temperatures below -5°C until the ice froze. Then, indoor irradiation test (see Photo 3) was conducted, and the surfaces were exposed to irradiation equivalent to one-fourth of the sunlight amount in summer (according to the weather data, the amount of sunlight at 7:00 am on winter solstice corresponds to one-fourth of the maximum sunlight amount on summer solstice). As a result, it took approximately 140 minutes for the snow on the surface of Vironment Pave not added with black pigment to melt away, whereas it took approximately 100 minutes in the case of the snow laid on Vironment Pave and dense graded asphalt pavement (see Fig. 6). We considered, therefore, that addition of the said amount of black pigment was expected to improve the delay in the start of snow-melting without impairing the temperature-reduction effect in summer.

Photo 3:Confirmation of snow-melting using indoor irradiation test

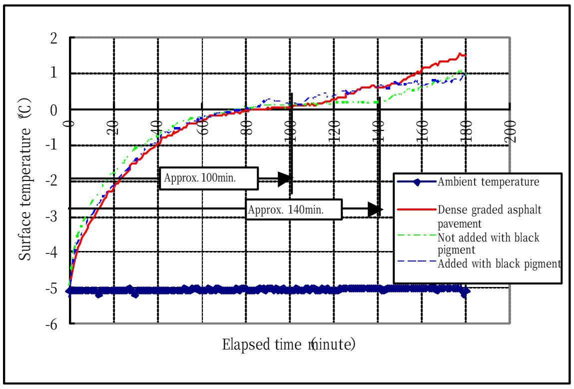


Fig. 6:Results of snow-melting test using sliced ice

6. TEST CONSTRUCTION AFTER IMPROVEMENT OF DELAY IN START OF SNOW-MELTING

Based on the results of the test construction in 2007, test construction of the pavement (3.5 × 26 = 91 m², t = 4 cm, base asphalt mixture containing 17 % of air voids) was implemented by using the cement milk improved in terms of delay in snow-melting. The pavement was constructed on July 8, 2008 in Hongo Parking Area (down highway) of Chugoku Highway when pavement repair work was under way in the section from Takada to Muikaichi (see Photo 4).

Photo 4: Pavement construction in parking area of Chugoku Highway

6.1 Results of Test Construction

In order to examine the method of penetration in the test construction, each batch mixer for cement milk used a different penetration method.

6.1.1 Temperature Within Pavement

Figs. 7 and 8 show the results of the measurement of temperature within the pavement (approximately 1.5 cm below the surface; the effect of reducing temperature can be regarded as almost identical with that obtained on the surface). During the period of the measurement, the maximum reduction in temperature was 15.3°C, which was obtained on the day following the day when water was sprayed (July 9), but most of the temperature reduction fell within the range between 6 and 9°C. On August 8, 2008, temperature reduction of 12.8°C was obtained. It was considered that this occurred due to the fact that there was continuous rainfall of 0.5 to 1.0 mm during the period between August 4 and 7 in 2008, which was followed by fine weather next day. From this, Vironment Pave is ssumed to have great effect of reducing road surface temperature if there is continuous rainfall irrespective of its amount.

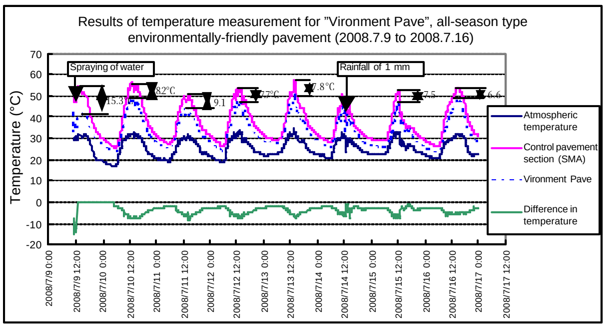


Fig. 7:Results of temperature measurement (July 9 to 16, 2008)

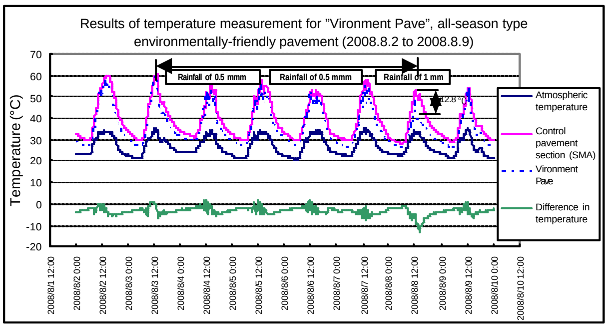
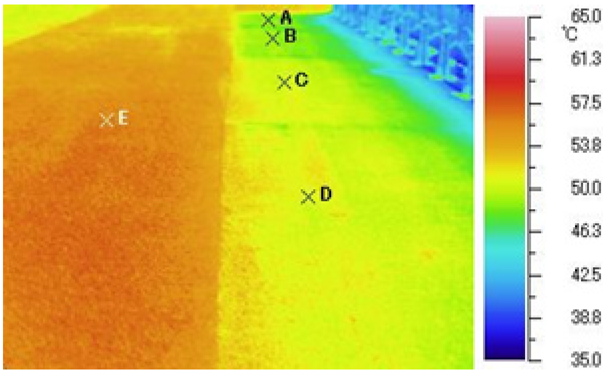


Fig. 8:Results of temperature measurement (August 2 to 9, 2008)

6.1.2 Temperature of Pavement Surface

The following is the results of surface temperature measurement made by using a thermography camera at 13:39 pm on August 1, 2008 (weather: fine, temperature: 34°C) (see Photo 5).



Point “A”: Vironment Pave
48.32°C -7.91°C
Point “B”: Vironment Pave
48.80°C -7.43°C
Point “C”: Vironment Pave
50.61°C -5.62°C
Point “D”: Vironment Pave
50.14°C -6.09°C
Point “E”: Control pavement section (SMA)
56.23°C

Photo 5: Results of surface temperature measurement with thermography camera

Temperature reduction of approximately 6 to 8°C was obtained as compared with the control pavement section. Sections “1” and “2” showed better results than Sections “3” and “4”, and it is assumed that more absorbent polymers concentrated near the surface in the case of Sections “1” and “2” due to the use of different penetration method.

6.1.3 Road Surface Management in Winter and Anti-Freezing Effect

As the road surface management for the test construction sections in winter, an amount of calcium chloride equivalent to 90 g/m^2 was sprayed on December 24, 2008, and the conventional road surface management procedure was followed thereafter.

During the period between January 10 and 11, 2009, there was cumulative snowfall of approximately 50 cm, and visual observation of the road surface condition was made under the temperature of -2.1°C at 7:33 am on January 11. It was confirmed that the snow on the test construction section was in sherbet form or melting, whereas the snow on the conventional asphalt pavement was compacted or frozen (see Photos 6 and 7).

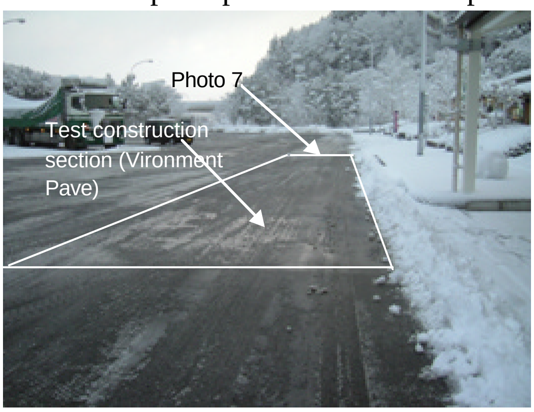


Photo 6: Road surface condition in winter

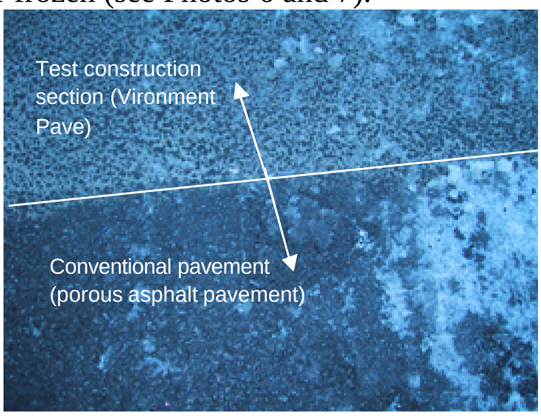


Photo 7: Difference in frozen road surface
<Upper side: Test construction section (Vironment Pave, snow in sherbet form)>
<Lower side: Conventional pavement (porous asphalt, compacted snow/ice plate)>

Then, salt concentration (in NaCl equivalent) was measured using refraction-type salt concentration meter, and 1.3% (N = 3) and 2.5% (N = 3) were obtained for the conventional asphalt pavement and the test construction section, respectively, with the latter nearly doubling the former. From these findings, it was confirmed that Vironment Pave was effective in preventing freezing.

7. CONCLUSION

As a result of the indoor tests and test construction for practical application, the following findings were obtained:

1) As a result of the indoor durability test, test simulating temperature reduction in summer, anti-freezing effect test simulating road surface in winter (adfreezing strength test), and other tests, it was confirmed that the pavement incorporated with absorbent polymer has superior effects both in reducing the pavement temperature and in preventing freezing.

2) As a result of test constructions conducted in Fukui Prefecture and Hongo Parking Area of Chugoku Highway, it was confirmed that the intended quality could be secured in in-situ situations.

3) In the test construction section in Fukui, it was found that it took more time for snow on Vironment Pave to melt away under sunlight due to the white color on its surface though its effect of reducing surface temperature in summer was confirmed.

4) The indoor simulation showed that addition of specified amount of black pigment was able to improve the delay in snow-melting without impairing the effect of reducing surface temperature. Then, reduction in road surface temperature by 12°C or more in summer and anti-freezing effect in winter were achieved in the test construction section in Hongo Parking Area of Chugoku Highway.

We will continue the follow-up study of Vironment Pave and examine the changes that may emerge over time in order to bring the quality of the all-season type environmentally-friendly pavement as near as possible to perfection, as it can serve as a strong measure against both "warming" and "snow".

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