Study on Ultra Thin Overlay Method Applicable in Medium to Low Temperature Range

K. Hatakeyama, T. Makabe and T. Emukai
Technical Research Institute, Maeda Road Construction Co., Ltd., Tsuchiura, Ibaraki, Japan

ABSTRACT: The thin layer overlay method that can be implemented at a low cost has become popular for maintenance and repair of the road pavement for these years.

However, in cases of the construction of an ultra thin layer of not thicker than 20 mm and of winter construction, as the temperature of the mixture, immediately after its spreading decreases rapidly, it is difficult to achieve required level of quality even with the warm mix technology. The conventional cold mix asphalt has superior workability at low temperatures, but its usages are limited because of its slow strength development after the construction.

Then the authors focused on a special kind of oil which reacts chemically by water addition and increases its viscosity, and by adding it with a reaction agent during the production of the asphalt mixture, ease of construction in medium-to-low temperature range and early strength development after the construction were ensured.

When this developed mixture is constructed into 10 mm thick construction layer under compaction at temperature of 60 degree, target quality for the degree of compaction and the strength at 30 minutes after the construction was obtained. Other properties were the same as those of hot mix asphalt.

KEY WORDS: Thin layer construction, cold laid mixture, cost reduction, chemical reaction

1 INTRODUCTION

Since the shortage of the budget for road maintenance has become serious for these days in Japan due to the budget cut for public work and impacts of the escalation of oil price, it is expected to be difficult to renew a huge volume of stock of roads in a planned manner which are getting close to the time for renewal. Especially for roads under the management of local governments, there are many places where maintenance and repair have not been done for long terms. In some of these places, although not yet being lead to a structural failure, minor cracks or surface roughness is observed and effective repairs are required.

As a popular repair method for these kinds of pavement damages, the thin layer overlay method which is able to be implemented at a low cost, can be considered. However, as the temperature of the mix decreases rapidly at the time of construction, this method is difficult to achieve required level of quality even though the warm mix technology is adopted.

There is another technology called cut-back asphalt mix which enables construction at the medium to low temperature range (60～100°C). This is advantageous in terms of construction, however, its oil components are hard to be volatilized and a condition of low viscosity of the binder lasts long, then how to gain initial strength remains to be an issue.

Then the authors focused on a special kind of lubricating oil with hardly-volatilizing property which reacts chemically by water addition and its viscosity increases, and developed an asphalt mix using this. This mix provides ease of construction in medium-to-low temperature range by adding the special lubricating oil and a reaction agent during its production. In addition, strength improvement is aimed to be achieved by spraying water from the roller at the compaction to cause chemical reaction between the special lubricating oil and the reaction agent and to increase the viscosity of the binder.

This paper reports results of the studies on the issues when this technology is applied to the ultra thin overlay method of 10～20 mm thickness and of the evaluation on workability through the trial paving, together with results of research conducted on the developed mixes.

2 TARGETS FOR THE DEVELOPMENT

Prior to the development, the authors carried out a trial to spread the hot mix asphalt of 160°C with 10 mm thickness at 5°C ambient temperature, and temperature of the mix decreased to around 60°C.

Based on this, development of the ultra thin overlay method (called as this method hereinafter) with asphalt mix using the special lubricating oil (called as the selected mix hereinafter) has been carried out aiming that sufficient workability and quality shall be kept even the temperature of mix decreased to as low as 60°C, that early traffic opening shall be made possible after completion of the construction, and that the durability level equivalent to that of ordinary dense-graded asphalt mix (13) (called as dense-graded (13) hereinafter) shall be obtained. The targets of the development of this method are shown in Table 1.

Table 1: Target of development of this method

Item	Target
Workability	Temperature at which rolling is possible: 60°C
Properties of mix	Equivalent to dense-graded (13)
Time of traffic opening	Equivalent to construction with ordinary hot mix
Versatility	Ordinary machines for production and construction to be used
Economical efficiency	Cost lower than that of thin layer overlay method

3 OUTLINE

3.1 Outline of Method Developed

Viscosity of the binder of the mix for thin layer construction is desirable to be kept low enough to be compacted sufficiently under rapid decrease in temperature after spreading, and to become as high as that of ordinary hot mix soon after finishing compaction. Figure 1 shows an ideal curve for the viscosity of the binder. If viscosity of the binder of the mix is controlled in this manner, degree of compaction at the thin layer construction can be ensured and early stabilization of the property of the mix can be achieved after its construction.

In this method, as shown in Figure 2, the special lubricating oil added at production of the mix forms a lubricating film of easily skidding nature on the asphalt coating and it provides ease of construction at the medium to low temperature range. In addition, chemical reaction between the special lubricating oil and reaction agent (powder form) is caused by sprayed water from the roller at the compaction, and designated degree of durability is gained early by increasing the viscosity of the binder.

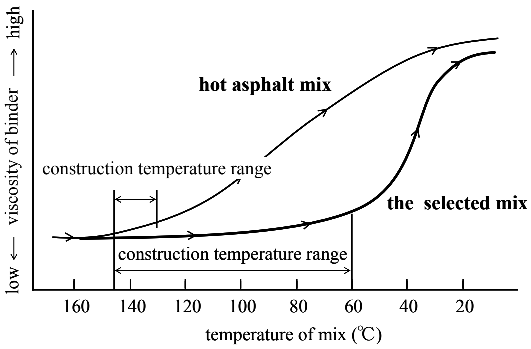

Figure 1: Ideal transition of binder viscosity for thin layer construction

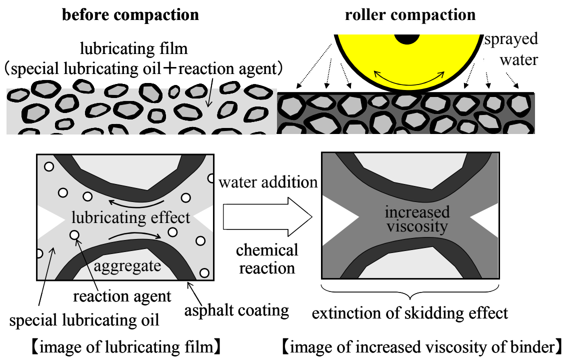

Figure 2: Conceptual drawing of developed method

3.2 Flow of the Study and Issues

Table 2 shows the issues to be studied. In the development of the selected mix, the major targets are set to be able to execute construction at the middle to low temperature range and to keep the same level of durability as that of dense-graded (13). Toward the practical application of the selected mix, on-site trial paving was carried out in order to verify the bonding capability to the existing road surface which was concerned in case of ultra thin layer construction being applied, or to verify the resistance to initial aggregate fretting relating to traffic opening.

In the study, the mix using the maximum aggregate size of 13 mm was defined first as a basis, then added amount of each additive was defined. After that, the mix using the maximum aggregate size of 5 mm was added to the study aiming for realization of the ultra thin layer construction and the basic property of the mix was understood.

Table 2: Issues to be studied

Item		Issues to be studied
Development of mix	Effects of additives	Improvement in compaction performance of hot mix
		Early strength development by water addition
	Properties of mix	Influences due to increased viscosity of binder
	Weather proofing	Verification on weather proofing of binder
Study for ultra thin layer construction	Workability	Keeping workability and quality in ultra thin layer construction
	Bonding capability with underlying layer	Keeping bonding capability with underlying layer at medium to low temperature range
	Traffic opening time	Verification of resistance to initial aggregate fretting

4 DEVELOPMENT OF THE MIX

4.1 Basic Proportion of the Mix and the Method of Making Specimen

Strength of the selected mix improves when the special lubricating oil and reaction agent in the mix contact with sprayed water from the roller at the compaction. Therefore considering the water permeability into the mix and the durability, aggregate grade was selected so as to keep porosity of 6%. As a result, component passed 2.36 mm sieve for the aggregate with the maximum size of 13 mm and 5 mm is set as 36% and 45%, respectively.

Since the selected mix was necessary to be heated at temperatures not lower than 120°C in order to remove water in the aggregate during the production at the plant, aggregate was heated at not lower than 120°C in the laboratory test. The method of preparing the specimen is as shown in Table 3, such that after the selected mix was filled in the mold, designated amount of water was added, and immediately after, compaction was carried out.

Table 3: Method of preparing specimen

Procedure		Condition
Mixing	(1) Dry mixing of aggregate	Aggregate temperature: ≧120°C
	(2) Addition of asphalt	St As60～80 temperature: 160°C
	(3) Addition of special lubricating oil	Internal division to binder amount
	(4) Addition of reaction agent	External division to amount of special lubricating oil
Production	(5) Filling into mold (formwork)	—
	(6) Addition of water	External division to amount of mix
	(7) Compaction	Marshall rammer (50 time both sides), roller compactor
	(8) Curing at constant temperature chamber	Air temperature 20°C, relative humidity 60% constant

4.2 Effects of Various Types of Additives

(1) Effect of Improving Workability

In order to evaluate the improvement of workability provided by the special lubricating oil, Marshall specimens were made by changing its added amount and the temperature at its compaction. Figure 3 shows the relationship between the temperature at compaction of Marshall specimens and the degree of compaction.

From the figure, the temperature at which 100% degree of compaction was achieved varied significantly from 145°C to 55°C as the amount of addition increased, and effects of improving workability due to the special agent was observed. This implies that compaction can be done at the target temperature of 60°C in case of 30% of binder amount.

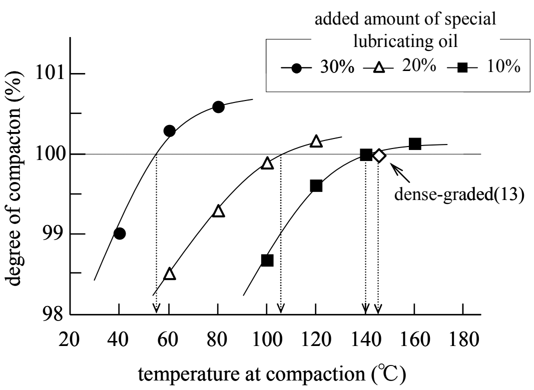

Figure 3:Improvement effect in workability due to special lubricating oil

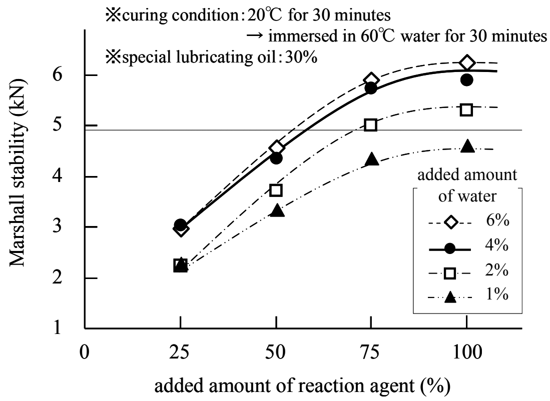

Figure 4: Relationship between added amount of reaction agent and Marshall stability

(2) Optimum Addition of Reaction Agent

As the reaction agent significantly affects the Marshall stability of the mix, the optimum addition for the special lubricating oil is necessary to be found in order to achieve high initial strength. Figure 4 shows the relationship between the addition of the reaction agent and Marshall stability. According to the figure, Marshall stability increased as addition of the reaction agent increased, and reached to an approximately constant value of not less than 75% addition of reaction agent, and therefore the addition of the reaction agent for the special lubricating oil was judged to be the optimum at 75%.

(3) Improvement Effects on Strength Development Due to Water

Based on the above results, improvement effects on strength development provided by water addition were studied. Figure 5 shows the amount of water addition and time-dependent change of the Marshall stability of the mix in terms of curing period.

From the figure, Marshall stability increases significantly as the water addition increases until about one day of curing, and almost the same value is indicated at 7-day of curing for specimens with water addition of 1～6% amount of mix. The case where the largest effect of Marshall stability improvement by water addition is exhibited, is that with not less than 4%, and this increase in Marshall stability of the mix was mostly terminated at 90-day.

In cases without water addition, reaction was promoted slowly with moisture in the air and values around 7kN were obtained at curing of 7-day. In actual construction outside, the improvement effects of strength development is expected to be further enhanced due to influences of rain water or others.

Water is necessary to be added at 4% to be permeated homogeneously into the mix in the case of Marshall stability test, but in the case of the thin overlay construction method, the amount of water required is expected to be smaller.

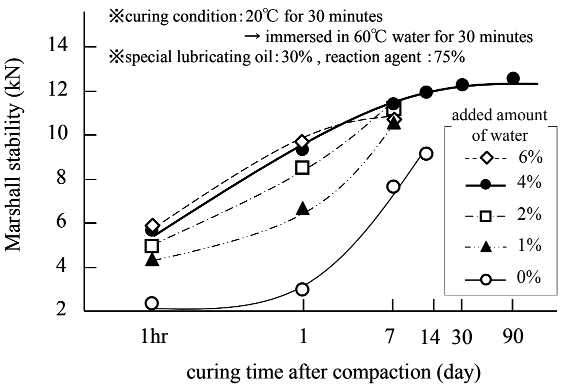

Figure 5: Time-dependent change of the Marshall stability

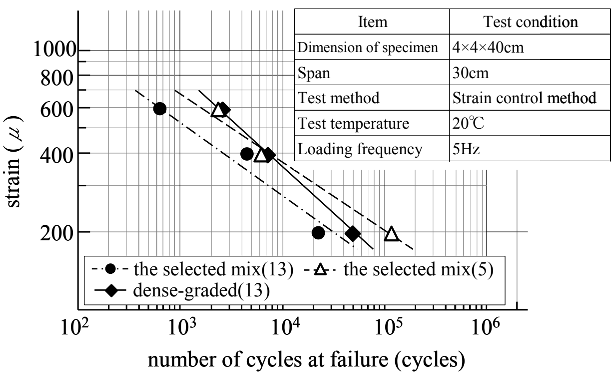

Figure 6: Results of fatigue resistance

4.3 Basic Properties of Mix

Based on this study result, specimens were made and cured with the conditions shown in Table 4 and tests on the properties of the mix were executed. Table 5 shows results of the property tests.

According to the table, Marshall stability, residual stability, and bending strain exhibited about the same values as those of dense-graded (13). For dynamic stability and aggregate fretting ratio by pressed tire, results indicating better performance than those of dense-graded (13) were observed.

As the dynamic stability showed a high value of not less than 6,000 times/mm and decrease in crack resistance was concerned, fatigue resistance was also studied. Figure 6 shows relationship between the number of cycles at failure and strain in the cyclic bending test. According to the figure, fatigue resistance of the selected mix was about the same value as that of dense-graded (13) and decrease in the crack resistance was not observed.

Although not shown in the paper, apart from above tests on the properties of the selected mix, good results have been obtained from laboratory studies with regard to the possibility of recycling or the applicability on the recycled hot asphalt mix. If this mix was kept warm with sheet without adding water, it was able to be used even at 8 hours after being shipped.

Table 4: Various conditions at property tests of mix

Item	Condition
Added amount of special lubricating oil (%)	30
Added amount of reaction agent (%)	75
Added amount of water (%)	4
Temperature at compaction (rolling) (°C)	60
Curing days before the test (day)	7

* cyclic bending test was conducted after the curing period (90-day) with which final strength was obtained.

Table 5: Test results on properties of mix

Items	The selected mix (13)	The selected mix (5)	Dense-graded (13)
Marshall stability (kN)	11.4	10.1	13.0
Flow value (1/100cm)	40	35	24
Residual stability (%)	84.7	94.1	81.3
Dynamic stability DS (times/mm)	6,000+		520
Dynamic stripping ratio (%)	6.7	8.2	7.5
Aggregate fretting ratio by pressed tire (type B) (%)	0.7	1.9	18.7
Bending strength(-10℃) (MPa)	5.3	5.4	7.6
Bending strain ($\times 10^{-3}$)	2.3	2.3	2.3
Bending stiffness (10^{3}MPa)	2.3	2.3	3.3

※ test method: in accordance with pavement investigation and test method guide and appendix of pavement performance evaluation method

4.4 Weather Proofing of the Mix

Weather proofing of the selected mix was evaluated by the bending test of the specimens that was exposed outdoor. Table 6 shows results of the bending test of the specimens that had been exposed outdoor for 6 months. As shown in the table, the specimens exposed for 6 months exhibited about the same test values as those cured indoor for 7 days prior to the exposure and no deterioration was observed on the mix as far as this test covered.

Table 6: Bending test results of specimens exposed outdoor

Items	The selected mix (13)		Dense-graded (13)	
	Before exposure	After 6-months exposure	Before exposure	After 6-months exposure
Bending strength (-10℃) (MPa)	5.3	5.6	7.6	7.0
Bending strain ($\times 10^{-3}$)	2.3	2.2	2.3	2.7
Bending stiffness (10^{3}MPa)	2.3	2.5	3.3	2.6

5 STUDIES AIMING FOR ULTRA THIN LAYER OVERLAY METHOD

With regard to issues in case that this technology was applied to the ultra thin layer overlay method, results of studies through indoor laboratory tests and on-site trial paving will be described as follows.

5.1 Bonding Performance with Underlying Layer

As this method requires roller compaction of the mix at a lower temperature than the ordinary construction method, concerns on decrease of the interlayer bonding capability with underlying layer were raised. Then considering that the lower limit of aggregate heating temperature is 120°C for this method, influences of difference in the rolling temperature when the selected mix is spread at temperature not higher than 100°C on the interlayer bonding capability with underlying layer was studied. Figure 7 shows the results of tensile test.

From the figure, it is found that the temperature at compaction had larger impacts on the tensile strength than the temperature at spreading, and that holding the temperature at compaction was important. As the upper layer has about the same bonding capability as that of dense-graded (13) at temperatures not less than 80°C, and has more than the same level of bonding capability as that of porous asphalt mix (13) , sufficiently high bonding capability can be achieved at target compaction temperature of 60°C for this method.

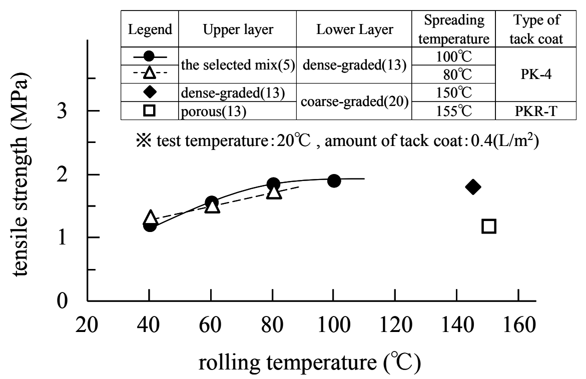

Figure 7: Results of tensile strength test

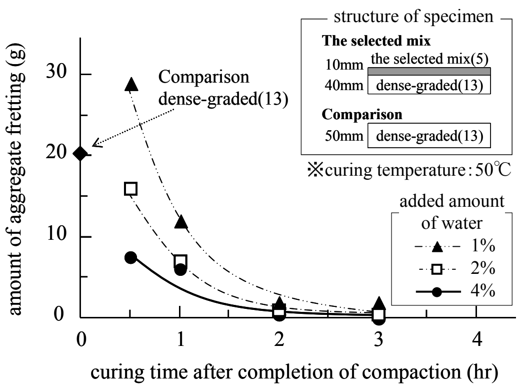

Figure 8: Results of tire stationary steering test

5.2 Time of Traffic Opening (Curing Time)

The condition of traffic opening after the paving for the hot mix is usually set as the temperature of the pavement surface being not higher than 50°C. However, as the selected mix is not of such type that strength increase is not caused by temperature decrease, but that strength development of the mix is caused by chemical reaction, time of the traffic opening is that when the designated durability is achieved. In addition, at the place where this method is applied, roughness of the surface caused by stationary steering or rapid braking is more concerned immediately after the construction than initial rutting.

Then, in order to verify the relationship between the curing time and the aggregated fretting, specimens were made and cured at 50°C until the testing time and the tire stationary steering test was executed by using an actual car shown in Photo1. Figure 8 shows results of the tire stationary steering test.

From the figure, with water addition of not less than 2%, the amount of aggregate fretting became not more than that for the case of dense-graded (13) at curing time of 30 minutes, and thus early traffic opening was confirmed to be possible.

※ contact pressure of tire : 0.37(N/mm^2) , handle operation : left and right one full turn

Photo 1: Status of tire stationary steering test

6 VERIFICATIONS FOR PRACTICAL APPLICATION

Based on the laboratory study results, on-site trial paving was executed to confirm its effects, and verification on the ease of mixing at an actual plant and workability and performance at site was carried out.

6.1 Outline of Trial Paving

Table 7 shows the outlines of the trial production and on-site trial paving. In the trial paving, target production temperature and construction temperature were set near the lower limit and the construction thickness was set to be the minimum construction thickness for this method of 10 mm, in order to evaluate the workability of this method under a severer condition.

Table 7: Outline of on-site trial paving

Item	Contents
Type of mix	The selected mix (5)
Location of construction	A road in author’s yard site (around 30 vehicles/day)
Scale of construction	3 m width x 15 m length
Construction thickness	10 mm (overlay)
Amount of tack coat	0.4 liter/m^2(PK-4)
Spreading machine	Domestic asphalt finisher (wheel type)
Rolling machine	4t combined roller (4 return trips)
Amount of sprayed water from roller	About same amount as ordinary construction

6.2 Results of Trial Paving

(1) Ease of Mixing
Figure 9 shows the production flow of the selected mix (5). It was confirmed that conditions of asphalt coating at unloading from the mixer was sufficient, and that the mix was produced actually at the pre-set parameters of the amount of binder and of aggregate grading from the results of asphalt extraction test.

(2) Workability
Photo 2 shows a status of construction at trial paving and Table 8 shows measured results of such as temperature at construction or degree of compaction. No dragging of the mix was seen at spreading and at rolling and workability was confirmed to be as sufficient as that for ordinary hot mix asphalt. Even with temperature decrease after the spreading, the degree of compaction of 98.1% was obtained and improvement in workability was confirmed under the

condition set this time.

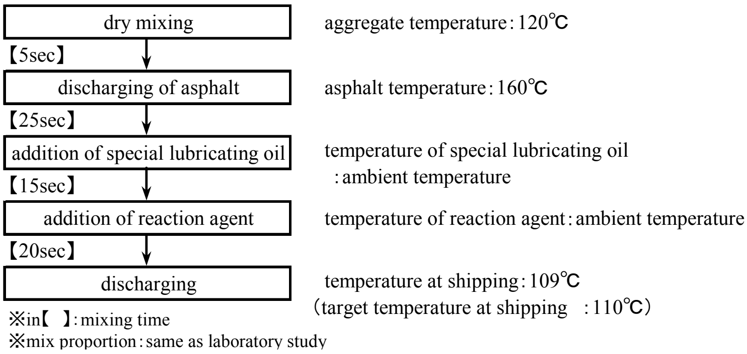

Figure 9: Production flow of the selected mix

Photo 2: Status of construction

Table 8: Result of construction management

Item		Measured result	Target value
Temperature at the start of construction	(℃)	98	100
Temperature at spreading	(℃)	89	90
Temperature at breakdown rolling	(℃)	63	60
Temperature at completion of rolling	(℃)	28	—
Ambient temperature at construction	(℃)	15	—
Average thickness	(mm)	9	10
Degree of compaction	(%)	98.1	—

(3) Time of Traffic Opening

Figure 10 shows results of the tire stationary steering test by using an actual vehicle on the road after the paving similar to the study conducted in the previous section 4.2. From the figure, it is found that better resistance against aggregate fretting than the case with dense-graded (13) was obtained after around 30 minutes curing after the completion of the rolling. From this, it can be said that traffic opening at 30 minutes after the completion of rolling is possible due to sprayed water at the rolling in this method.

The amount of sprayed water at the rolling was about 0.5 liter/m^2 and it was about 2 % as ratio to the mix weight if converted into the amount of water addition. From the figure, as resistance against aggregate fretting was found to be significantly improved in a short period, it was confirmed that about 2% of water added could permeate sufficiently over whole layer and that it promoted strength development.

(4) Bonding Capability with Existing Pavement

When tensile strength test on samples cored from the site was conducted, tensile strength of not less than 1.6MPa was obtained and sufficient bonding capability between the selected mix and the existing layer was confirmed.

(5) Performance

As dynamic coefficient of friction (at 40km/h) was 0.42 immediately after the construction and was 0.58 at 6 months after the construction, it was confirmed that sufficient resistance against slipping was kept. No case of roughness or crack of the road surface due to stationary steering of tires or sudden braking, occurred during one year period after the completion of the construction.

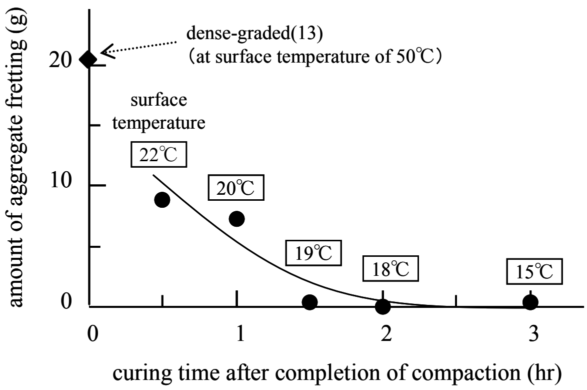

Figure 10: Results of tire stationary steering test at site

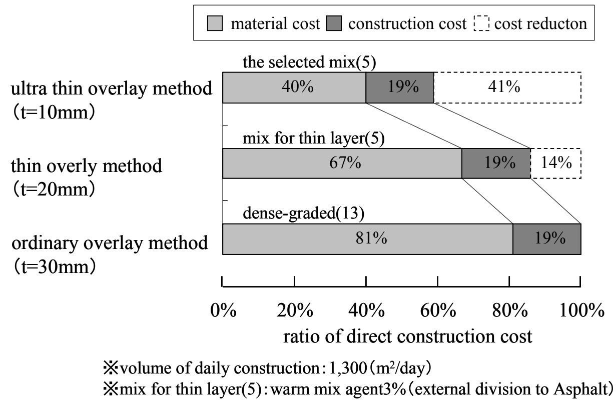

Figure 11: Comparison of economical efficiency

7 ECONOMICAL EFFICIENCY

Figure 11 compares the direct construction costs of this method and of various types of overlay methods. As the selected mix uses such materials as the special lubricating oil, material unit prices for this mix increase compared with the case with ordinary hot mix asphalt. However, as the amount of the mix to be used for the same construction area for this method with which 10 mm thickness construction becomes possible, is drastically smaller than the case with other overlay methods, it is possible to repair with the lesser amount of resources and at the lower cost. From the figure, if the cost of the overlay method with 30 mm thickness is considered as 100%, only 14 % cost reduction will be expected for the case of ordinary thin overlay method, but 41% cost reduction will be expected for this method.

8 CONCLUSIONS

Through the attempt to achieve practical application of the ultra thin overlay method, findings obtained from the study results based on the laboratory tests and on-site trail paving are shown as follows;

1) As skidding property is provided on the asphalt coating by using the special lubricating oil, it is possible to ensure quality even though temperature at rolling of the mix is around 60°C.
2) By sprayed water from the roller at compaction, the special lubricating oil and the reaction agent react chemically and viscosity of the binder is increased, which makes possible to open traffic after around 30 minutes of curing time.
3) Properties and weather proofing are about the same as those of dense-graded (13) and degradation of properties due to increasing viscosity of the binder is not observed.
4) With this method, around 30～40% of cost reduction is expected compared with various overlay methods, and thus this method can also be said as economically advantageous.

REFERENCES

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