Journal of Materials and Engineering Structures

Research Paper

Study on Wash-out of Asphalt Mixture Caused by Repeated Heating and Cooling Immersion Test

Hiroki Imai [a,*], Mohd Rosli Mohd Hasan [b], Nguyen Quang Phuc [c], Hiromitsu Nakanishi [d], Akihiro Kato [e], Tomohiro Ando [a]

[a] *Engineering research laboratory, TAIYU Kensetsu Co., Ltd., 6-12 Jubancho, Nakagawa-ku, Nagoya, Japan*

[b] *School of Civil Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal Penang, Malaysia*

[c] *University of Transport and Communications, No.3 Cau Giay St., Lang Thuong Ward, Dong Da Dist., Ha Noi, Vietnam*

[d] *TAIYU Kensetsu Co., Ltd., 5-14-2 Kanayama, Naka-ward, Nagoya, Japan*

[e] *TAIYU Vietnam Co., Ltd., Room 302, 3 Floor – 101 Lang Ha Building, Lang Ha Dong Da District, Hanoi, Vietnam*

ARTICLE INFO

Article history:

Received : 7 November 2020

Revised : 18 December 2020

Accepted : 18 December 2020

Keywords:

Wash-out

Bipolar anti-stripping agent

Static Stripping test

Repeated Heating

Cooling Immersion test

ABSTRACT

Stripping generates within the asphalt pavements due to continuous effect of moisture has been one of the concerns by the road authorities worldwide. Without a proper treatment, it could cause potholes and lower the bearing capacity of asphalt pavements. With regard to this, it is well known that the bipolar anti-stripping agent is effective to prevent the stripping due to its electrochemical bonding characteristics between aggregate and asphalt. Wash-out is a dynamic water action that could strip the asphalt mortar from pavement surfacing. Such distress spotted on many roads, whereby, granite aggregates are normally used as the main material in asphalt mixtures. In this study, the experimental work is focused on stripping phenomenon caused by multiple moisture conditioning cycles at 80 °C, and a newly developed evaluation protocol using a Repeated Heating and Cooling Immersion test is adopt-ed. The Wash-out, which is closely associated with stripping, is studied to evaluate the resistance of asphalt pavement against moisture damage. This study is a laboratory scale evaluation and the phenomenon in the field is not yet adequately considered. The repeated heating and cooling immersion procedure is an accelerated strip-ping conditioning without applying an external force. It is clarified that the resistance to the Wash-out of asphalt mixture is improved with the presence of the bi-polar anti-stripping agent, known as Tough Fix Hyper at the rate of 0.15% or more.

F. ASMA & H. HAMMOUM (Eds.) special issue, 3rd International Conference on Sustainability in Civil Engineering ICSCE 2020, Hanoi, Vietnam, J. Mater. Eng. Struct. 7(4) (2020)

* *Corresponding author.*
E-mail address: imai-hiro@taiyu.co.jp

e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

1 Introduction

With regards to the moisture-related pavement distress, there is a severe stripping that only the coarse aggregates remain on the pavement surface after asphalt mortar has washed out, which leads to the situation that the fine aggregates separated from the asphalt mortar are depositing on the edges of the road. This phenomenon can be known as a Wash-out (Photo. 1). The Wash-out can be seen not only on the roadway but also on the sidewalk and shoulder, and it can be often seen on the old sidewalk. It should hinder the comfortable driving and walking for road users and pedestrians. If proper countermeasures would not be taken, the Wash-out would grow into pot-holes would make the pavement life short. In the case of the Wash-out on the porous asphalt pavement, the permeability and the low noise function would be lost due to clogging by the fine aggregates stripped. Technically, the Wash-out is closely related to stripping that takes place due to continuous exposure to water actions and abrasion between tires and pavement surface. However, the Wash-out phenomenon is very often seen even on the sidewalk and the shoulder which are not subjected to the friction of the tire as mentioned above. Therefore, it would be better to think that something that is not related to the external force would mainly cause the Wash-out. Therefore, the authors reconsidered the stripping phenomenon and observed in detail the conventional static stripping test performed in a laboratory. As a result, the authors verified experimentally that the immersion in hot water was only a "trigger" in the stripping process and the stripping would be mainly caused by sudden shrinkage of asphalt coated around aggregates, which would be caused by a sudden temperature change from a high-temperature state to a low-temperature state by like a sudden rainfall. In this study, the anti-stripping performance of asphalt mixture is evaluated by giving repeated hot immersion and cool immersion. As a result, the Wash-out phenomenon was also able to be evaluated.

Photo. 1 – Wash-out detected on the asphalt pavement surface

2 Previous Studies of Stripping on Asphalt Mixtures Introduction

2.1 Past research on stripping of asphalt mixture

The stripping of asphalt mixture is generally evaluated by the degree of strength reduction via the Residual Stability test (ASTM D 1599), and the Modified Lottman test (AASHTO T283). In Japan, it is also tested using the Immersed Wheel Tracking test. It is assessed by the ratio of stripping area to the specimen cross-section after being subjected to the repeated loading for 6 hours in hot water bath at 60 °C.

In 2011, the Dynamic Asphalt Stripping Machine (DASM) test was developed by researchers at University Sains Malaysia (USM). In that test, the porous asphalt mixture is exposed to a continuous water action mimicking rainy condition at 40 °C, with rainfall intensity equivalent to 5,400 *mm*/*h* for 7 days. The moisture susceptibility is evaluated by the Indirect Tensile Strength ratio between conditioned (*wet*) and unconditioned (*dry*) samples [1].

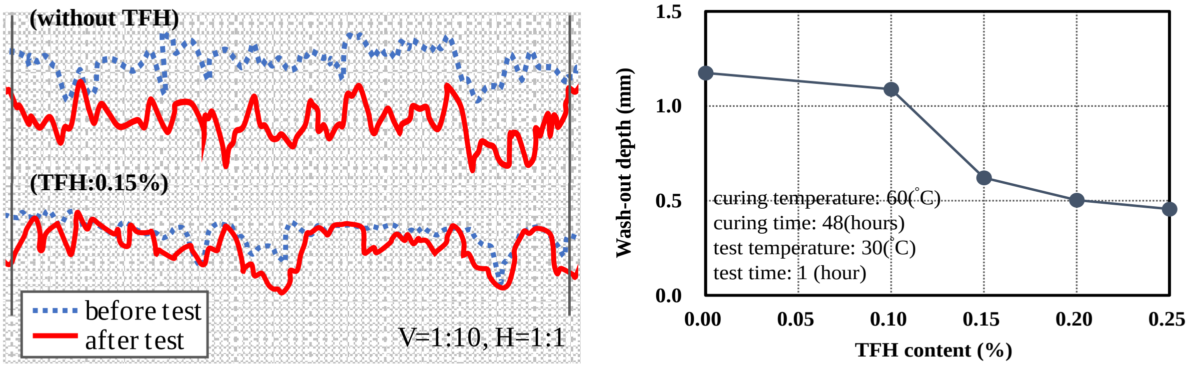
However, the aforementioned methods are inadequate to study the Wash-out phenomenon. A new method should be initiated to further understand the mechanism involved and the effect of the Wash-out on the asphalt pavement surface.

2.2 Past research at Taiyu Kensetsu

The authors clarified that the bipolarity anti-stripping agent "Tough Fix Hyper (TFH)" could be used to improve the anti-stripping performance based on the assessments conducted using Residual Stability test, Modified Lottman test, and Immersed Wheel Tracking test [2, 3].

During the ICPT conference held in Malaysia in 2019, the Wash-out phenomenon was carried out using the equipment that can repeatedly give the torsional load on the surface of the specimen in the warm water at 30 °C. In this test, the average wearing depth was evaluated as the Wash-out depth by comparing the surface shape of the specimen before and after the test as shown in Fig. 1(a). Fig. 1(b) shows the relationship between the TFH content and the Wash-out depth. The result shows that the Wash-out depth is significantly reduced by adding TFH at 0.15% or more [4].

However, as mentioned earlier, the Wash-out occurs not only on the areas designated as wheel paths but also sidewalks and shoulders. Therefore, it is necessary to investigate the Wash-out on the specimen without applying the external force.



(a) Difference in shape of surface (b) Wash-out depth vs. TFH content

Fig. 1 – Test result of Immersed Wearing test

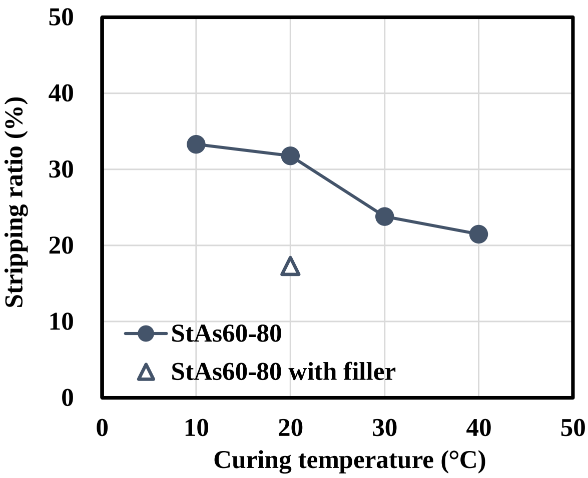
3 Hypothesis and experiment of Wash-out

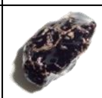
3.1 Wash-out using high-pressure water

Based on the hypothesis, the Wash-out would take place after introducing to heavy rainfall, whereby, the high-pressured water was tentatively tried. The slab shape specimen with the size of 30 × 30 × 5 *cm* is exposed to a 80 °C hot water shower with the shower intensive of 2,500 *L/h* for 6 hours during this test. But, unfortunately, the Wash-out phenomenon didn't take place as expected.

3.2 Effect of temperature gap on Static Stripping test results

After long periods of immersion in hot water, asphalt stripping easily generates. However, the authors believe that the immersion in hot water would be nothing more than a "trigger" of the stripping process. And the authors considered the stripping would be initiated by the asphalt-film coated around the aggregate subjected to sudden shrinkage by a sudden change in temperature from high temperature to low temperature.



Cool water (°C)	10	20	30	40	20 (+filler)
Physical observation (Stripping)					

※ Coarse aggregate (Granite): 100g
Asphalt (StAs60-80): 5.5g
Filler ($CaCO_3$): 2.0g (in case of addition of filler)

Fig. 2–Result of Static Stripping test

It is a situation like where the surface of the pavement is cooled by a sudden squall. Firstly, the study confirmed whether the hypothesis is right by carrying out the Static Stripping test by changing the temperature of the water for cooling after the asphalt-coated aggregates have been immersed in hot water. In the Static Stripping test referred to here, granite coarse aggregates (9.5 – 12.5 *mm*) coated with 5.5% asphalt binder with penetration grade 60 – 80 (StAs60-80) stay in hot water at 80 °C for 30 minutes. And such coarse aggregates are transferred to cool in cool water at 10, 20, 30, and 40 °C for 30 minutes. The stripping ratio is calculated and quantified visually. Moreover, when applying a filler (CaCO3) to asphalt, the strip-ping ratio is measured at 20 °C cooling temperature. By contrasting the effect with the case without a filler, the inclusion of a filler is explained. Fig. 2 displays the Static Stripping test results. As shown in Fig. 2, the stripping ratio becomes larger along with lowering the temperature for the cooling. It is clarified that the resistance to moisture damage is improved by incorporating CaCO3 into the asphalt mixture. That is because the apparent viscosity of the asphalt increases by adding a mineral filler into the asphalt.

3.3 Wash-out and Repeated Heating and Cooling Immersion test

The finding of previous section indicate that a single cycle of Static Stripping test of the asphalt mixture may not be severe because the filler works to prevent the asphalt mixture stripping. Therefore, in order to produce a stripping process like the Wash-out on an asphalt mixture, it would be necessary to give the asphalt mixture the repetition of heating and cooling.

In this study, the authors have established an acceleration test in which the Marshall specimen is repeatedly subjected to heating and cooling immersion. In particular, the Marshall specimen is immersed in hot water at 80 °C for 1 hour, and then rapidly, the specimen is immersed in cool water at 20 °C for 30 minutes.

The above process is designated as one cycle, and it is repeated up to 20 cycles. In addition, the remaining specimens are continuous immersed in hot water at 80 °C for 5, 10, 15 and 20 hours to validate whether the repetition of heating and cooling immersion affects the generation of stripping. Table 1 shows the condition of the Repeated Heating and Cooling Immersion test.

Table 1 – Test condition of Repeated Heating and Cooling Immersion test

Item			Condition
Repeated heating and cooling immersion	Immersion with heating water	(°C)	80 (1 hour)
	Immersion with cooling water	(°C)	20 (30minutes)
	Number of cycles		20
Continuous immersion	Immersion time	(hours)	5, 10, 15, 20 (80°C)

4 Repeated Heating and Cooling Immersion test

4.1 Asphalt mixture used in this research

Granite contains a lot of SiO_2 and is classified as an acid rock that easily causes stripping. Such granite is normally being used as the aggregate for pavement in ASEAN countries. In this study, dense-graded asphalt mixtures based on the Malaysian specification were prepared by using granite aggregates form Malaysia, and such the Marshall specimens are used for the Repeated Heating and Cooling Immersion test.

Table 2 – Mix gradation of dense graded asphalt mixture using Granite (AC14)

Sieve size (mm)	20	14	10	5	3.35	1.18	0.425	0.15	0.075
Passing weight percentage (%)	100	96.3	79.9	57.1	47	26.5	17	8.8	6.0
Gradation envelope (lower-upper limits, %)	100	90 – 100	76 – 86	50 – 62	40 – 54	18 – 34	12 – 24	6 – 14	4 – 8

In addition, $CaCO_3$ filler and StAs60-80 made in Japan were used. The anti-stripping agent (TFH) was used at the rate of 0.15% and 0.25% prior to addressing the effect of anti-stripping performance via repeated heating and cooling immersion. Table 2 shows the mix gradation for the preparation of dense-graded asphalt mixture samples. Table 3 shows the properties of asphalt with incorporation of TFH to StAs60-80.

Table 3 – Properties of straight asphalt 60 – 80 with Tough Fix Hyper (TFH)

TFH content	(%)	0.0	0.10	0.15	0.20	0.25	Reference standard
Penetration	(1/10 *mm*)	65	63	62	62	61	ASTM D5
Softening point	(°C)	47.0	48.5	48.5	48.0	48.0	ASTM D36
Ductility	(cm)	100+	100+	100+	100+	100+	ASTM D113
Viscosity at 135°C	($mPa \cdot s$)	366	366	368	368	362	ASTM D4402
Viscosity at 160°C	($mPa \cdot s$)	132	128	128	130	131	

4.2 Evaluation method of Wash-out

A digital image of the specimen's surface after each cycle is used to assess the Wash-out effect due to the Repeated Heating and Cooling Immersion test. The area where asphalt coating remains is transformed to black on the digital image and the area where stripping occurs is transformed to white. The white area (stripping area) ratio to the entire specimen's digital surface is measured as Wash-out ratio (Fig. 3).

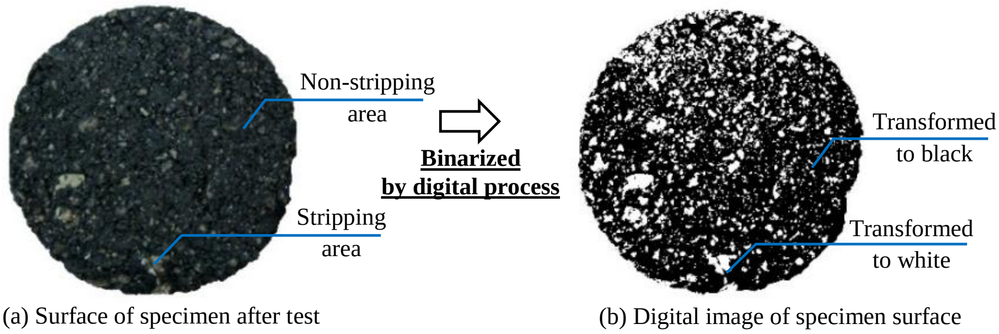
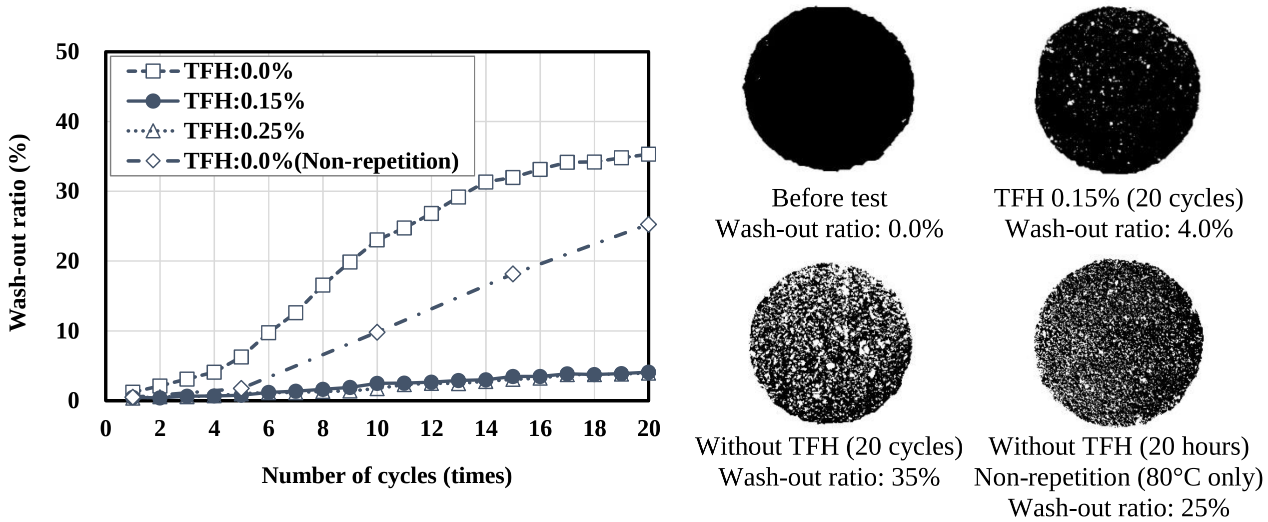


Fig. 3–Evaluation procedure of Wash-out after the test

4.3 Resistance to Wash-out caused by repeated heating and cooling immersion

Fig. 4(a) shows the Wash-out ratio vs. the number of cycles at different dosages of TFH. The data shown here were the average values of the three specimens, and their coefficient of variation was 0.17 at the maximum although there were differences in each cycle. As shown in the figure, the Wash-out ratio increases along with the in-crease in the number of cycles. The Wash-out ratio without TFH shows an exponential increase, while with the TFH, the increment is only 5% or less at 20 cycles. The Wash-out ratio with TFH is about 1/7 as compared to the sample without TFH. The result indicates that the addition of TFH improves the resistance to the Wash-out on the surface of the asphalt mixture. The immersion duration is set to be equivalent for all samples at 80 °C in the Repeated Heating and Cooling Immersion test. As shown in Fig. 4(a), the Wash-out ratio of the specimen under the repeated heating and cooling immersion is severer than the sample exposed to the continuous immersion. As a result, it can be proven that the stripping is accelerated under the repeated heating and cooling immersion.

Fig. 4(b) shows the binarized digital images of specimens at different conditions. It is possible to visually confirm that the stripping is accelerated by subject to the repeated heating and cooling immersion and the improvement effect with the incorporation of TFH. However, it is necessary to further study the test conditions such as a higher number of conditioning cycles and temperatures.



(a) Wash-out vs. number of cycles (b) Binalised digital image of specimen

Fig. 4 – Result of Repeated Heating and Cooling Immersion test

5 Conclusions

Based on the experimental works conducted, this study can be concluded as follows;

The stripping of asphalt mixture can be mimicked by heating and cooling immersion, and the severity can be increased and accelerated by a large temperature gap or a higher repetition of the heating and cooling immersion.

The Repeated Heating and Cooling Immersion test is an accelerated stripping conditioning protocol that mainly focus on temperature gap without applying an external force. This test can be used to simulate the Wash-out phenomenon on-site. However, further study should be conducted to understand the phenome-non.

The resistance to the Wash-out has been improved by the addition of TFH at the rate of 0.15% or more, which are similar to those obtained in the previous study.

Acknowledgements

Authors would like to acknowledge the assistance provided by Taiyu Kensetsu Co., Ltd. that enables this study to be conducted. The fellowship provided by the Matsumae International Foundation (MIF) to the former visiting scientist, Dr Mohd Hasan is also highly appreciated.

References

[1]- M. Hamzah, M.M. Hasan, M. van de Ven, J. Voskuilen. Development of dynamic asphalt stripping machine for better prediction of moisture damage on porous asphalt in the field. In: Proceedings of the 7th RILEM International Conference on Cracking in Pavements. Springer, 2012, pp. 71-81.

[2]- H. Imai, N.Q. Phuc, H. Nakanishi, T. Ando., Anti-stripping agent for hot mix asphalt pavement, in International conference on sustainability in civil engineering. The transport journal: Hanoi, Vietnam. (2016) 45-48.

[3]- H. Imai, N.Q. Phuc, H. Nakanishi, A. Kato, Evaluation of anti-stripping property of modified asphalt under severer conditions, in International conference on sustainability in civil engineering. The transport journal: Hanoi, Vietnam. (2018) 198-203.

[4]- H. Imai, H. Nakanishi, Effect of anti-stripping agent with bipolarity to strip-ravelling damage caused by surface shear strength, in International conference on road and airfield pavement technology. 2019, Kuala Lumpur, Malaysia.