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Stripping resistance evaluation of bead coating via Hamburg wheel tracking test and image analysis

함부르크휠 시험과 이미지 분석을 통한 비드코트 탈리 저항성 평가

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ABSTRACT

PURPOSES : The aim of this study is to evaluate the stripping resistance of a bead coating via the Hamburg wheel tracking test and image analysis.

METHODS : First, the stripping resistance of the bead coating was evaluated via the Hamburg wheel tracking test. A pneumatic wheel with a load of 175±2 N was used to simulate repeated skid cycles. Several bead coating mixtures with different numbers of coating layers, i.e., zero, one, two, three, and four layers, i.e., zero, one, two, three, and four layers,were conducted. Finally, an image analysis program was developed to analyze surface images captured from the Hamburg wheel tracking test.

RESULTS : The results show that the samples with more coating layers exhibit higher stripping resistance. After 500 stripping cycles, the percentage of bead loss is 4% to 28%. At 80% bead loss, the mixture with one coating layer presents more skid cycles than the control sample without a coating layer.

CONCLUSIONS : Incorporating a coating layer can improve the stripping resistance of glass beads under repeated skid cycles. Additionally, an image analysis program is established in this study to determine the percentage of bead loss caused by the stripping test.

Keywords
Asphalt pavement, Bead coating, Stripping test, Hamburg wheel tracking test, Image analysis program

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1. Introductuon

1.1. Literature review

Pavement friction plays an important role in keeping vehicles on the road. Friction gives drivers the ability to control their vehicles in a safe manner. In general, the higher the friction of the pavement-tire interface, the more control the driver has over the vehicle (National Academies of Sciences, Engineering, 2009). However, pavement friction has been gradually decreased during service life. In addition, weather condition also affects friction of surface road such as snow, ice, and drain. The research from Zhao et al. showed that road friction of snow road and ice road were 10 and 6 times less than dry asphalt road, respectively (Zhao et al., 2017). Friction enhancement not only improve safety but also provide comfort for the drivers. Therefore, improving pavement friction is a hot topic that attracted many researchers.

In last decades, the common method to improve or maintain pavement friction is the application of very-high quality aggregate to the pavement using a polymer binder at existing or potentially high crash areas (Hatherly & Young, 1976). In recent years, epoxy formulation, and durable aggregate production are improving safety at critical high-crash spot-locations on concrete and asphalt pavements. For examples, using glass bead as a road marking material as well as improving friction of pavement in the study of Burghardt et al, (Burghardt et al., 2022). Among durable aggregates, glass bead is more focused due to its properties such as chemically stable, so it has excellent water resistance, alkali resistance, acid resistance, chemical resistance, solvent resistance and heat resistance. Wenzal et al. introduced a technique to coat glass beads on the surface of sample. In Wenzal's study, the percentage loss of glass beads was determined through abrasion test (Wenzel et al., 2022). It should be noted that sliding of tire on the road surface is an important factor that caused the stripping of glass bead. Hamburg wheel tracking test is a common test to simulate rolling tire on the road surface (Phan et al., 2022). Aktas et al. performed HWTT to evaluate chip seal retention performance (Aktaşet al., 2013). However, there is still lack of research on the striping of coated beads caused by sliding tires.

Therefore, this research was conducted to test and evaluate the resistance to stripping of the beads coatings, the test results could be applied to design and predict the maintenance time of the beads coating layers in actual conditions.

1.2. Research contents

This study evaluated the stripping resistance of the beads coating by using the Hamburg wheel tracking test. Different mixtures of the beads coating layer were examined to evaluate effect of coating on stripping resistance of glass beads. An image analysis program was developed based on Python programming language to analyze surface conditions after subjected to Hamburg wheel tracking test. The remaining of beads on the surface were detect and the percentage loss were calculated. The promising results will provide tools for the analysis, evaluation on anti-stripping ability of the beads coating layer under real-world conditions.

2. Materials – Sample preparation

2.1 Materials

2.1.1. Beads properties

Glass beads for pavement marking are usually made from recycled glass such as recycled window glass, recycled car glass, etc. They are ground to the desired dimension and to make the beads irregularly round in a short time, the glass beads are heated at approximately 1200 ℃ (Wenzel et al., 2022).

In terms of classification, glass beads for pavement marking are divided into two types: sprinkled glass, which is sprinkled on the surface through a bead dispenser of paint sprayer; pre-mixed glass beads, which have been thoroughly mixed with the coating before being applied (Xu et al., 2021).

In this study, the glass beads were spread on the surface of the base coating layer. The size of glass beads ranged from 0.8 – 1.2 mm. Because glass is a chemically stable material, it has excellent water, alkali acid, chemical resistance, solvent and heat resistance. In addition, the stress in all directions is the strongest due to the shape of a ball is round.

2.1.2. Beads Coating process

The beads coating process is currently carried out mainly by spreading glass beads onto the surface of the coating layer (paint coating layers, epoxy coating layers, etc...). The beads coating layer was shown in Figure 1. To limit the stripping of the glass beads, coating films are applied on the surface. This method ensures that the glass beads are 100% surrounded, increasing the adhesion between the glass beads and the binder, thereby increasing the stripping resistance (Mirabedini et al., 2019).

2.2. Sample preparation

The samples were compacted by Super Gyration Compactor (SGC). Polymer Modified Asphalt (PMA) dense grade with PG 76-22 asphalt binder was used. The air void of samples was controlled at 7±1%. All sample has dimension of 150 mm in diameter and 62 mm in the height. The sample was shown in the Figure 2.

After compaction, the cylindrical samples were cut into the size of the Hamburg Wheel Tracking test (AASHTO-T324-11, 2011). Then, these samples were dried at room condition for at least two days before applying bead coating. The cutted samples were shown in the Figure 1. For each coating mixture, four cylindrical samples were prepared, which resulted in two sets of Hamburg wheel tracking samples.

In this experiment, beads coating layers were considered, including 0, 1, 2, 3, and 4 coating layers. The sample surfaces are shown in Figure 1. A thin epoxy coating layer was applied on the surface of the sample. The glass beads were spread on the surface using an air-pressure-gun as shown in the Figure 3. After that, the bead coating layer was cured using UV lamp. An 8 W output LED lamp was employed to irradiate UV rays with a wavelength of 395 nm for 5 seconds at 10 cm from the surface.

Fig. 1 Apply coating layer

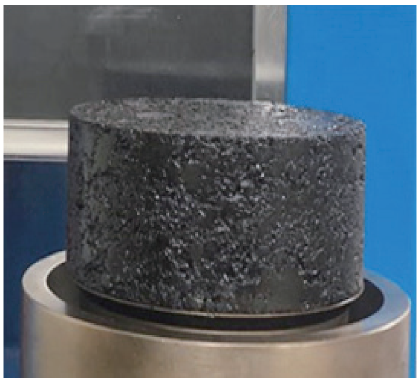

Fig. 2 Sample compaction using Super Gyrator Compactor

Fig. 3 Bead coating process

3. Test Methods

3.1. Hamburg wheel tracking test

The Hamburg wheel tracking machine was used to conduct the stripping test. The Hamburg wheel load was 175±2N. The test temperature was controlled at 25 ℃. The wheel speed was controlled at 52 passes/min. A pneumatic wheel has a dimeter of 200 mm and a width of 50 mm as shown in Figure 4. For each mixture, 5 stripping levels were considered, including 100, 200, 300, 400, and 500 cycles. For a mixture with 0 coating and 1 coating layer, the skid cycles were applied until the bead loss reaches 80%. The surfaces were captured with an interval of 100 skid cycles. The surface at each testing level was captured using a digital camera as shown in Figure 5.

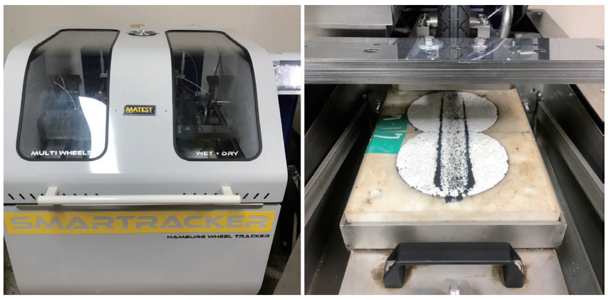

Fig. 4 Hamburg wheel tracking machine and skid test set up

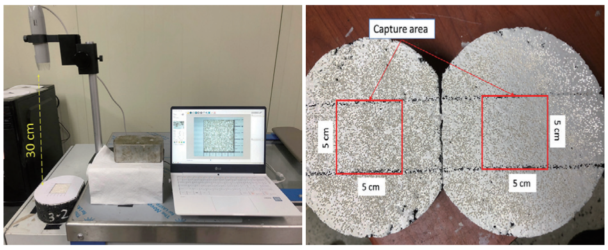

Fig. 5 Surface capturing setup

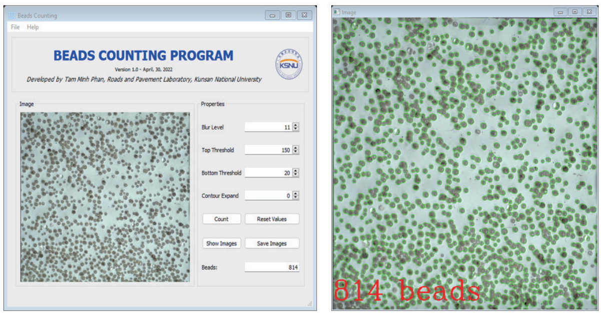

Fig. 6 Image analysis program

3.2. Image analysis

The captured images were analyzed by an image analysis program. The program was developed using Python programing language. For each image, the number of beads was counted and the percentage of bead loss was calculated by equation (1).

$$L = \frac{N_0 - N_k}{N_0} \times 100 \quad (1)$$

Where,

L (%) is the percentage of bead loss,

N_0 is the number of beads before testing,

N_k is the number of beads after k cycles.

In general, an image includes three channels: Red, Green, and Blue (called RGB). Each channel contains a matrix of values. With the adjusting of these values, the bead can be detected. The algorithm of the beads counting program can be simplified in the following steps:

- Firstly, convert the image to grayscale (Phan et al., 2022) The purpose is to reduce the algorithm and reduces computational requirements. The luminosity method is more popular in converting images to grayscale. The equation is shown below.

  $$RGB\ to\ Gray : Y \leftarrow 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B$$

Where, Y is the grayscale channel, R, G, and B are red, green, and blue channels, respectively.

- Secondly, the blurring method was applied to remove small dust or unwanted particles. This is done by convolving an image with a normalized box filter. It simply takes the average of all the pixels under the kernel area and replaces the central element. A 3x3 normalized box filter (K) would look like the below

  $$K = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

- Thirdly, detection of contour. This step is to determine the bead properties such as position, number of beads, the size of beads. Based on the previous study (Suzuki et al., 1985), the algorithm can be simplified as determines the surroundness relations among the borders of a binary image.
- Noted that "Beads counting program" is an automatic process. However, to improve the accuracy of the detection, several trackbars were added to the program, including an upper threshold, lower threshold, and blur scale. By adjusting trackbars the lower threshold and upper threshold, as well as the blur scale of the image were changed.

4. Results-discussion

After the conduction of the Hamburg wheel tracking test, the samples were image analyzed by the image analysis program. The results were obtained in two parts: Beads loss at 500 skid cycles; Skid cycles at 80% bead loss.

4.1. Bead loss at 500 skid cycles

The bead loss of coating samples is shown in Figure 7. Overall, the bead loss increases with the increase in the number of skid cycles as shown in Figure 8, 9. Sample with 0 coating layer showed the highest percentage of bead loss, which was approximately 28% after 500 cycles. Meanwhile, the 4 coating layers sample presented the lowest bead loss, which was approximately 4% after 500 cycles. It was found that the more coating layers lead the better stripping resistance.

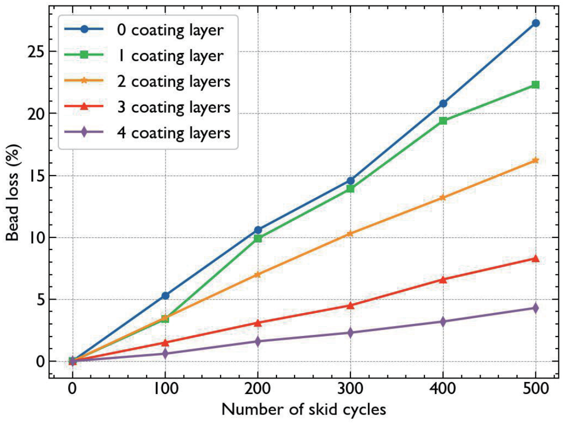

Fig. 7 Bead loss of coating samples

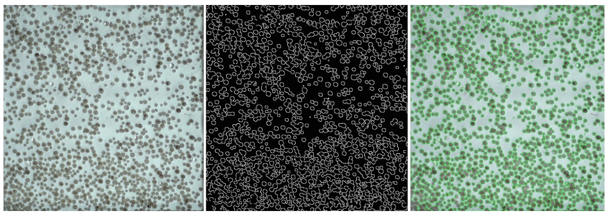

Fig. 8 Image processing of sample 1 at 0 cycle

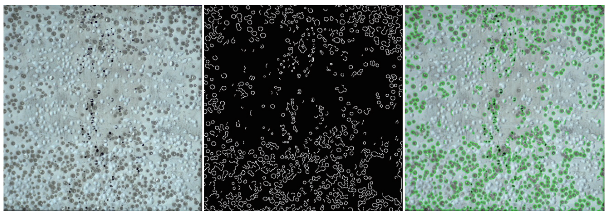

Fig. 9 Image processing of sample 1 at 500 cycles

As shown in Figure 8, 9, 11, and 12 the image analysis program presented a high accuracy. In these figures, the first picture is the captured surface of the sample after passing the Hamburg wheel tracking test; the second picture is the picture in grayscale; and the third picture that has shown the contour of the beads to determine the position, the number of beads, the size of beads. The detection of beads loss and the actual bead loss were consistent. The bead loss was concentrated in the middle of the specimen. This is because the middle of the sample was an area that was highly exposed to with tire surface. It should be noted that the high accuracy of image analysis process was depended on the quality of the captured image. To acquire this purpose, the distance between the camera and the surface of the sample was fixed at 30 cm, and the light was controlled.

4.2. Skid cycles at 80% bead loss

In this test, the number of skid cycles was recorded until the bead loss reached 80%. Two mixtures were examined, including control (0 coating layer) and 1 coating layer. Overall, the 1 coating mixture presented a higher number of skid cycles than that of without coating. The 1 coating mixture requires more than 3500 skid cycles to acquire 80% bead loss. Meanwhile, the control mixture only reached 2500 cycles. In the case of the developed method (top coating type), it was

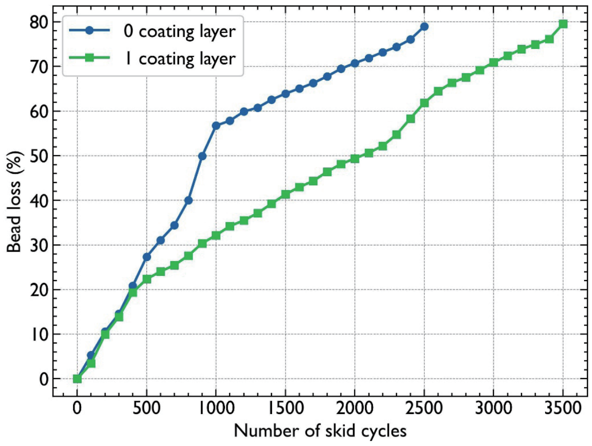

Fig. 10 Skid cycles vs. bead loss

verified that it was effective in preventing the glass beads from falling off or stripping.

The images at 80% bead loss are shown in Figure 11 and Figure 12.

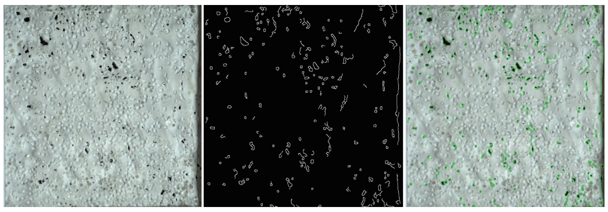

Fig. 11 80% bead loss of 0 coating sample (at 2500 skid cycles)

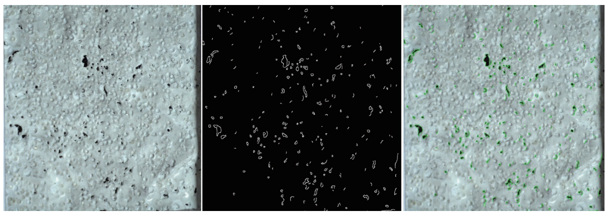

Fig. 12 80% bead loss of 1 coating sample (at 3500 skid cycles)

5. Conclusions

In this study, the image analysis program was set up to analyze and process the image results after performing the Hamburg wheel tracking test, thereby evaluating the stripping resistance of the beads coating in asphalt pavement. The highlights of this research are summarized as below:

- The results showed that the use of coating layers was more effective in protecting the glass beads from stripping compared to control without coating layers.
- Increase in number of coating layers could enhance the stripping resistance of beads coating. Especially, the percentage loss of sample with 4 coating layers was only 4% after 500 stripping cycles.
- Sample with 0 and 1 coating layer reached 80% of bead loss after 2500 and 3500 cycles, respectively.
- An image analysis program was successfully developed to determine the loss content of glass beads due to stripping and also to examine the number of glass beads remaining in the bead coating, thereby can simulate and predict stripping resistance under real-world conditions.

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REFERENCES

AASHTO-T324-11 (2011). *Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)*.

Aktaş, B., Karaşahin, M., Saltan, M., Gürer, C., & Uz, V. E. (2013). Effect of aggregate surface properties on chip seal retention performance. *Construction and Building Materials,* 44, 639-644.https://doi.org/https://doi.org/10.1016/j.conbuildmat.2013.03.060

Burghardt, T. E., A. Pashkevich, D. Babic, H. Mosbock, D. Babic, and L. Zakowska. (2022). *Microplastics and road markings: the role of glass beads and loss estimation*. Transportation Research Part D, Vol.102, pp.103123. https://doi.org/10.1016/j.trd. 2021.103123

Hatherly, L. W., & Young, A. E. (1976). The Location and Treatment of Urban Skidding Hazard Sites. *TRB Research Record.*

Mirabedini, S. M., Zareanshahraki, F., & Mannari, V. (2019). *Enhancing thermoplastic road-marking paints performance using sustainable rosin ester*. Progress in Organic Coating, pp. 105454. https://doi.org/10.1016/j.porgcoat.2019.105454

National Academies of Sciences, Engineering, and M. (2009). Pavement Friction and Surface Texture. *In Guide for Pavement Friction.*

Phan, T. M., Le, T. H. M., & Park, D.-W. (2022). Evaluation of cracking resistance of healed warm mix asphalt based on air-void and binder content. *Road Materials and Pavement Design,* 23(1), 47-61. https://doi.org/10.1080/14680629.2020.1829010

Suzuki, S., K. Be. Topological structural analysis of digitized binary images by border following, *Comput. Vision, Graph.* Image Process. 30 (1985). pp.32-46. https://doi.org/10.1016/0734-189X(85)90016-7

Wenzel, K. M., T. E. Burghardt, A. Pashkevich, and W. A. Buckermann. (2022). *Glass Beads for Road Markings: Surface Damage and Retroreflection Decay Study*. Appied Sciences, Vol. 12, No. 4, pp. 2258. https://doi.org/10.3390/app12042258

Xu, L., Z. Chen, X. Li, F. Xiao. (2021). Performance, environmental impact and cost analysis of marking materials in pavement engineering, the-state-of-art. *Journal of Cleaner Production*, Vol. 294, p.126302 https://doi.org/10.1016/j.jclepro.2021.126302

Zhao, Y.-Q., Li, H.-Q., Lin, F., Wang, J., & Ji, X.-W. (2017). Estimation of Road Friction Coefficient in Different Road Conditions Based on Vehicle Braking Dynamics. *Chinese Journal of Mechanical Engineering*, 30(4), 982-990.