AN EXPERIMENTAL STUDY ON THE PERMANENT STRAIN OF DENSE-GRADED ASPHALT AND POROUS ASPHALT USING UNIAXIAL CYCLIC COMPRESSION TEST WITH CONFINEMENT

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Abstract

This study investigated the permanent strain of dense-graded asphalt and porous asphalt material using uniaxial cyclic compression test with confinement. Based on the test results, the comparison of the permanent strain was carried out. The results showed that the permanent strain resistance of porous asphalt material was better than that of the dense-graded asphalt material. In addition, the use of higher performance-graded asphalt binder improved remarkably the permanent strain resistance of porous asphalt material. The analysis of the two prediction models showed that the power model performed better in prediction of the permanent strain. In future, more studies need to be conducted to investigate the effect of other factors such as moisture, freeze/thaw cycle on the mechanical performance of the porous asphalt material.

Keywords: *Dense-graded asphalt; porous asphalt; permanent strain.*

1. Introduction

In urban areas where low impact development strategies increase for preserving the natural hydrologic regime of watershed by managing stormwater as close to its source as possible, permeable pavement systems have been used widely. In the permeable pavement systems, the porous asphalt (PA) is often used for the surface layer. It is designed with a high porosity so that it can allow water to infiltrate through. In general, the PA material supports the permeable pavement systems not only for load-bearing capacity but also for the drainage. As a popular and affordable material in decades, PA material has been used [9]. Under the traffic loads, permanent strain or rutting of the PA material occurs and is considered as one of the main distresses of pavement system [6, 10].

Until now, there have been many studies of the permanent strain of PA material. Afonso et al. (2016) studied the permanent strain of PA material designed with

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cellulosic fibers [1]. The results of permanent strain were provided by wheel tracking tests. This study pointed out that the addition of cellulosic fibers in the PA material increased remarkably permanent strain resistance of PA material. In addition, this study figured that PA material with higher percentage of binder performed better in resistance to permanent strain. They recommended to use the addition of cellulosic fibers to archieve the better mechanical performance of PA material.

Another study of Wang et al. (2018) focused on the permanent strain of PA material in the case of working in summer weather [10]. The results indicated that the permanent strain of PA material is more sensitive to temperature and traffic load than the moisture. The authors concluded that PA material showed a good resistance to permanent strain. Recently, Kusumawardani and Wong (2020) investigated the effect of aggregate shape on the permanent strain of PA materials [8]. The specimens were designed with binder PG-76 and fabricated by gyratory compactor. The results showed that aggregate shape affected significantly the permanent strain of PA material. The analysis figured that to increase the permanent strain resistance of PA material, the aggregate with cubical shape was recommended to use.

Literatures showed that the permanent strain of PA material strongly depends on the binder, material type, aggregate shape and environmental conditions. To investigate the permanent strain of PA material, laboratory tests were often carried out. Until now, there are not many studies show a comparison of the permanent strain of the dense-graded asphalt and PA material. Thus, this study was conducted to fill this gap.

2. Permanent strain of asphalt material

Permanent strain is the most important distress that takes part in failure of pavement systems. According to [11], in pavement system, permanent strain can appear in subgrade, subbase, base or even the upper layer due to the values of stress's propagation caused by the tire pressure. According to BS EN 12697-25:2016 [4], the cumulative permanent deformation at *n* loading cycles as defined in Eq. (1):

$$u_n = |h_o - h_n| \tag{1}$$

where u_n is the cumulative permanent deformation of the test specimen after n loading cycles, (mm); h_o is the mean vertical position of the upper loading plate as measured by displacement transducers directly after end of preload of the test specimen, (mm); h_n is the mean vertical position of the upper loading plate as measured by displacement transducers after n loading, (mm).

The permanent strain of the test specimen after n loading cycles is determined in Eq. (2):

$$\varepsilon_n = \frac{u_n}{h_o} \tag{2}$$

where ε_n is the cumulative permanent strain of the test specimen after n loading cycles.

3. Materials, Equipment and Test Procedure

The specimen preparations and experiments in this study were conducted in Green Infrastructure - Low Impact Development Center at Pusan National University, South Korea. To investigate the permanent strain of the dense-graded asphalt and PA material, this study experimented on the two asphalt materials. The dense-graded asphalt material in this study was fabricated based on Korean Standard (KS) F 2349 "Hot mix asphalt mixture" for WC-3 mixture [7] with asphalt binder PG 64-28 and porosity as 4%. On the other hand, the PA20 material were fabricated with asphalt binder PG82-34 and porosity as 20%. The particle size distribution of the two asphalt materials are presented in Fig. 1.

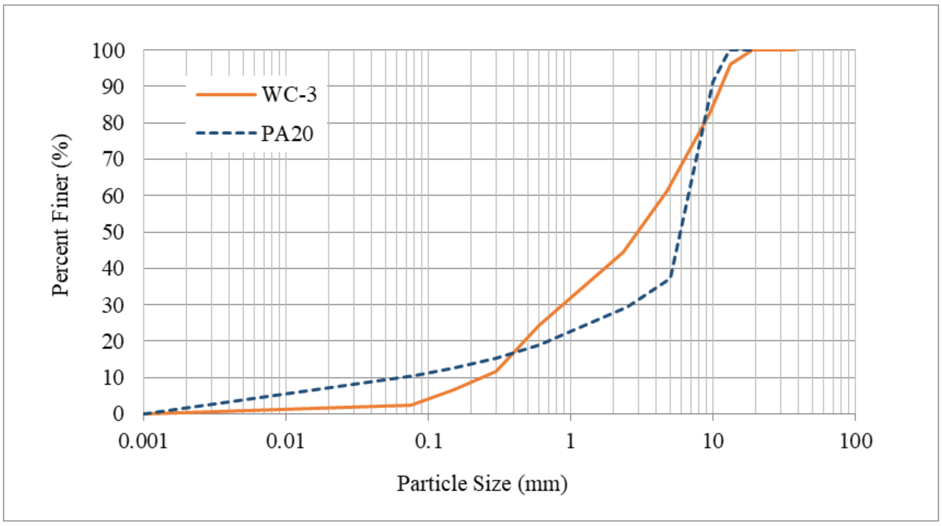

Fig. 1. Particle size distribution of WC-3 and PA20

Both mixtures were designed with same binder content as 5%. After finishing fabricating mixtures, two specimens with diameter as 150 mm and height as 60 mm for each mixture were prepared for testing.

Permanent deformation tests were carried out with a Material Testing Systems (MTS) 370.10 servo-hydraulic testing system, in Fig. 2a, which includes a load frame rated at 100-kN with 150-mm stroke actuator, 25-kN load cell and a temperature chamber. While the MTS machine provided the cyclic axial loads to the specimen, the temperature chamber provided the desired temperature to the specimen. In this study, the cyclic load and temperature values were applied according to the method A_1 in the standard BS EN 12697-25:2016. To record the deformation of the test specimens, two linear variable differential transformers (LVDT) were used, in Fig. 2b. For each mixture, two identical specimens were fabricated and experimented.

(a) *(b)*

Fig. 2. Test setup for the permanent deformation

Before the test, specimens were conditioned in the temperature chamber at 35^{o}C for one day. This process was operated to ensure that all the specimens could have the same testing condition. After that, WC-3 specimens were tested first, and then the PA20 specimens. During the experiment, values of cyclic loads, LVDT signals, and temperature were recorded continuously.

4. Results and Discussion

For each asphalt material, two identical specimens were tested. The permanent strain results for each material were the average of them. The comparison of permanent strain results for the two asphalt materials at 35^{o}C are shown in Fig. 3. Based on the results, it can be seen that the permanent strain of WC-3 specimen is consistently higher than that of the PA20 specimen. This behavior is similar with that in previous studies of

[9-11]. It could be attributed to the use of binder. While the WC-3 mixture used the binder as performance-graded asphalt binder (PG) 64-28, the PA20 mixture used PG 82-34. Therefore, the WC-3 mixture has a lower permanent strain resistance than the PA20 mixture does at high temperature. It can be concluded that asphalt material designed with higher PG may provide better permanent strain resistance. It is consistent with the conclusion of [1].

In addition, due to the use of open-graded aggregate material in the mixture, PA20 mixture itself obtains the load bearing-capacity from particle to particle contact. Therefore, PA20 mixture may provide a high permanent strain resistance.

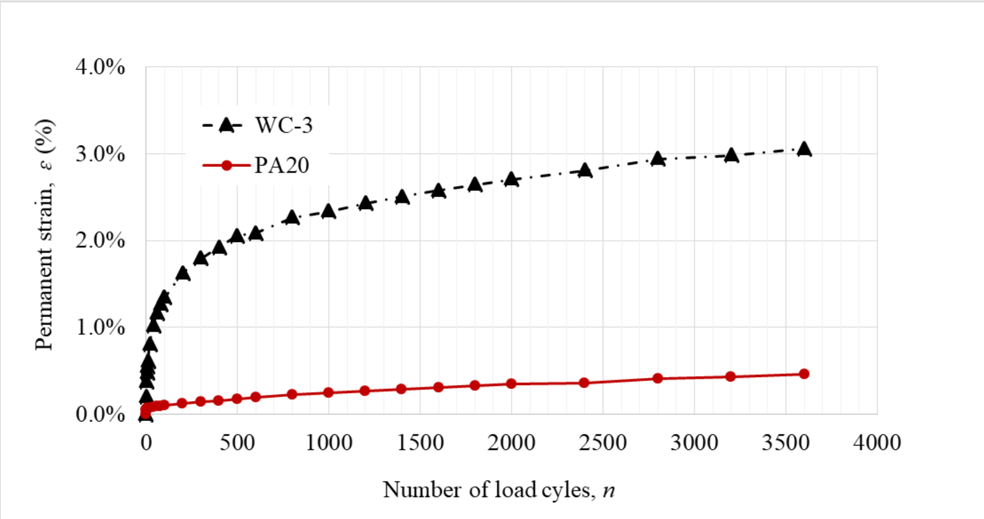

Fig. 3. Permanent strain results for the two mixtures

To determine the model parameters, two models were used in this study, the linear and power model. These two models are presented in the standard BS EN 12697-25:2016 [4], which is shown in Eq. (3) and (4). Based on these models, the model parameters were determined by least square fitting curve method.

$$\varepsilon_n = A_1 + B_1.n \tag{3}$$

where A_1 and B_1 are the regression coefficients.

$$\varepsilon_n = A.n^B \tag{4}$$

where A and B are the regression coefficients.

The permanent strain of test data and predicted data for the two materials in the first and second model are displayed in Fig. 4, 5, 6 and 7 below.

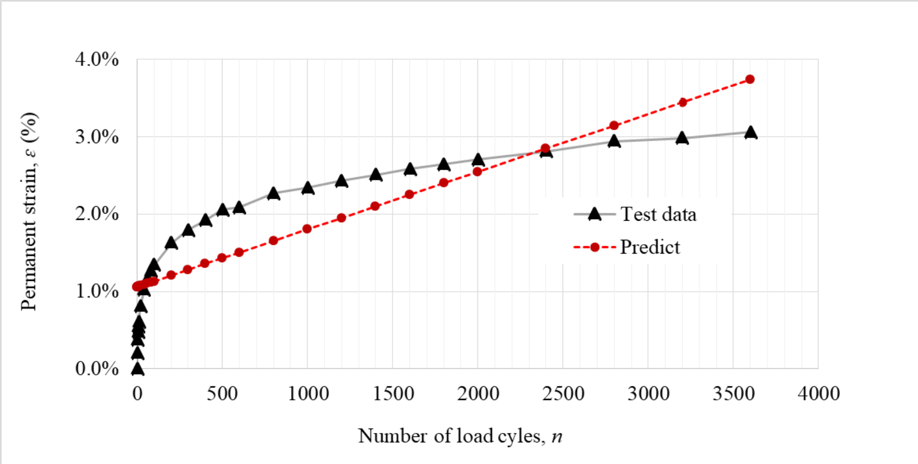

Fig. 4. Predicted and test data of permanent strain for WC-3 mixture in the first model

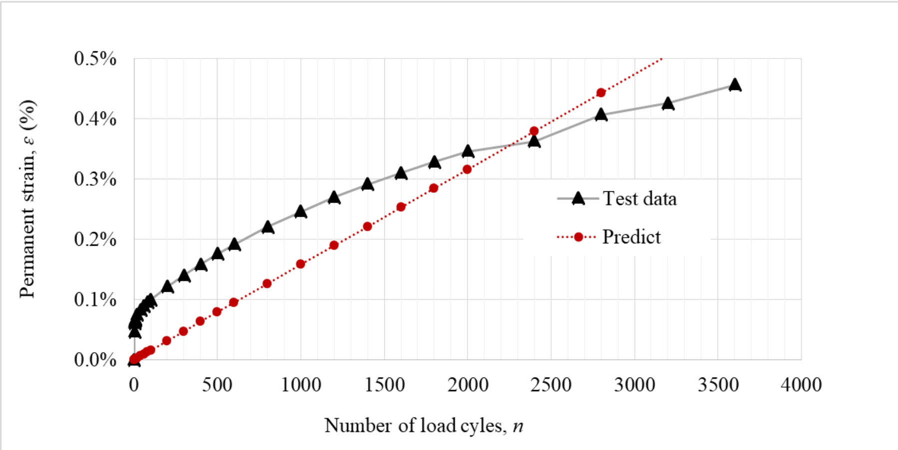

Fig. 5. Predicted and test data of permanent strain for PA20 mixture in the first model

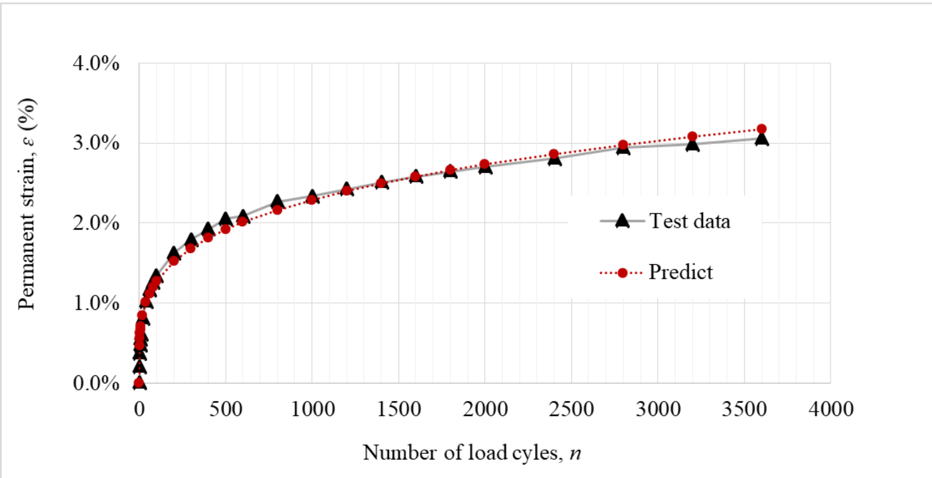

Fig. 6. Predicted and test data of permanent strain for WC-3 mixture in the second model

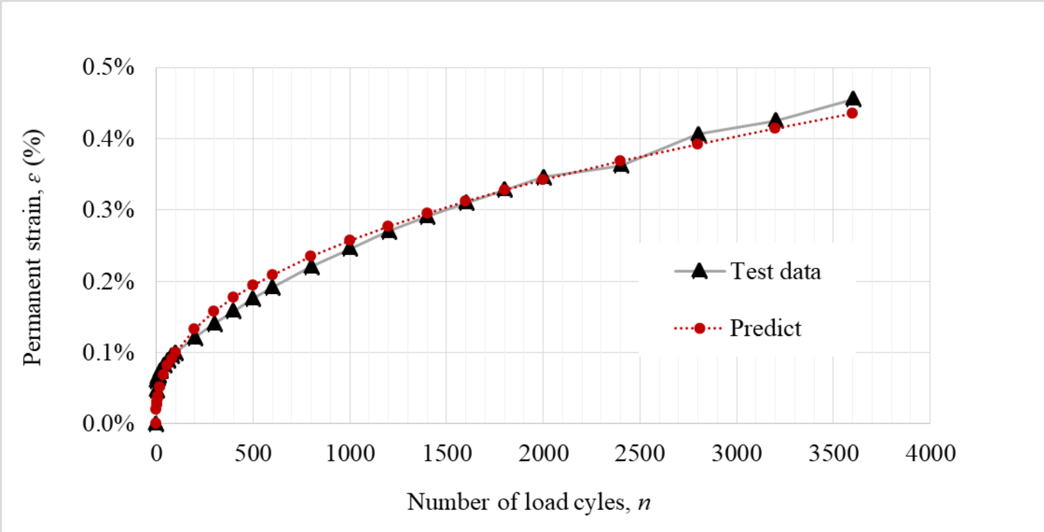

Fig. 7. Predicted and test data of permanent strain for PA20 mixture in the second model

Based on the results, it can be seen that the permanent strain predictions of the first model did not compare well with the test data. In contrast, those of the second model compared well with the test data. The finding in this study is that the second model perform better to predict the permanent strain for the asphalt concrete mixtures. The model parameters of the two models are given in the Table 1 below.

Table 1. Model parameters for the two materials

Material	BS EN 12697-25:2016 model					
	First			Second		
	A_1	B_1	R^2	A	B	R^2
WC-3	0.01057	7.4e-6	0.63	3.93e-3	0.254	0.99
PA20	0.0067e-6	1.58e-6	0.83	0.152e-3	0.410	0.98

5. Conclusion

This study investigated the permanent strain of dense-graded asphalt WC-3 and porous asphalt PA20 materials using uniaxial cyclic compression test with confinement. Based on the test and analysis results, the following conclusions were drawn:

The permanent strain resistance of PA20 mixture is better than that of the WC-3 asphalt material. It could be attributed to the use of higher performance-graded asphalt binder. The finding is that the use of higher performance-graded asphalt binder improved remarkably the permanent strain resistance of PA material.

This study used two models in the standard BS EN 12697-25:2016 [4] to predict the permanent strain of the two asphalt materials. The model parameters were determined by least square fitting curve method. The analysis showed that between the two models used to predict the permanent strain of asphalt materials, the power model performed better.

In future, more studies need to be conducted to investigate the effect of other factors such as moisture, freeze/thaw cycle on the mechanical performance of the PA material.

References

[1] Afonso, M. L., Dinis-Almeida, M., & Fael, C. S. (2017). Study of the porous asphalt performance with cellulosic fibres. *Construction and Building Materials, 135,* pp. 104-111.

[2] Ahmed, M. A., & Attia, M. I. (2013). Impact of aggregate gradation and type on hot mix asphalt rutting in Egypt. *International Journal of Engineering Research and Applications (IJERA), 3(4),* pp. 2249-2258.

[3] El-Basyouny, M., & Mamlouk, M. (1999). Effect of aggregate gradation on the rutting potential of Superpave mixes. *78th Annual Meeting of the Transportation Research Board*. Washington, DC.

[4] EN, B. 12697-25: 2016 Bituminous Mixtures. Test methods. Cyclic compression test

[5] Epps, A. L., Hand, A. J., Epps, J. A., & Sebaaly, P. E. (2001). *Aggregate contributions to the performance of hot mix asphalt at WesTrack Aggregate contribution to hot mix asphalt (HMA) performance: ASTM Internationa*l.

[6] Garba, R. (2002). *Permanent deformation properties of asphalt concrete mixtures*, Dotoral thesis, Department of Road end Railway Engineering, Norwegian University of Science and Technology.

[7] Korean Standards Association. KS F 2349. (2010) *Hot Mix Asphalt Mixtures*.

[8] Kusumawardani, D., & Wong, Y. (2020). The influence of aggregate shape properties on aggregate packing in porous asphalt mixture (PAM). *Construction and Building Materials, 255,* p. 119379.

[9] Wang, X., Chen, X., Dong, Q., & Jahanzaib, A. (2020). Material Properties of Porous Asphalt Pavement Cold Patch Mixtures with Different Solvents. *Journal of Materials in Civil Engineering, 32(10),* p 06020015.

[10] Wang, X., Gu, X., Ni, F., Deng, H., & Dong, Q. (2018). Rutting resistance of porous asphalt mixture under coupled conditions of high temperature and rainfall. *Construction and Building Materials, 174,* pp. 293-301.

[11] White, T. D. (2002). Contributions of pavement structural layers to rutting of hot mix asphalt pavements. *NCHRP report 468,* Transportation Research Board, Washington, D.C, USA.

NGHIÊN CỨU BIẾN DẠNG KHÔNG HỒI PHỤC CỦA BÊ TÔNG NHỰA CHẶT VÀ BÊ TÔNG NHỰA RỖNG BẰNG THÍ NGHIỆM NÉN DỌC TRỤC TẢI TRỌNG LẶP HẠN CHẾ NỞ HÔNG

Tóm tắt: *Nghiên cứu này khảo sát biến dạng không hồi phục của vật liệu bê tông nhựa chặt và bê tông nhựa rỗng bằng thí nghiệm nén dọc trục tải trọng lặp hạn chế nở hông. Dựa vào kết quả thí nghiệm, sự so sánh của biến dạng không hồi phục được thực hiện. Kết quả nghiên cứu thực nghiệm cho thấy, khả năng chống biến dạng không hồi phục của bê tông nhựa rỗng tốt hơn bê tông nhựa chặt. Ngoài ra, việc sử dụng cấp PG cao hơn cải thiện đáng kể khả năng chống biến dạng không hồi phục của bê tông nhựa rỗng. Kết quả phân tích hai mô hình dự đoán biến dạng không hồi phục cho thấy, mô hình hàm mũ cho kết quả dự đoán tốt hơn. Trong tương lai, nhiều nghiên cứu cần được thực hiện để khảo sát sự ảnh hưởng của các nhân tố khác như độ ẩm, thời tiết đến tính chất cơ học của bê tông nhựa rỗng.*

Từ khóa: Bê tông nhựa chặt; bê tông nhựa rỗng; biến dạng không hồi phục.

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