

DOI: <https://doi.org/10.24425/amm.2024.147821>L.A. SOFRI^{1,2*}, D. GANESAN¹, M.M. AL B. ABDULLAH^{2,3}, CHEE-MING CHAN⁴,
M.H. OSMAN⁴, J. GARUS⁵, S. GARUS⁵

THE EFFECT OF RECYCLED HIGH-DENSITY POLYETHYLENE (HDPE) AS AN ADDITIONAL BINDER IN POROUS ASPHALT PAVEMENT

Porous asphalt has excellent permeability and larger air voids. Due to the low stability strength of asphalt binder with aggregates, Malaysia uses porous asphalt roads for lightweight vehicle road transportation. Numerous studies indicate utilizing Recycled High-Density Polyethylene in porous asphalt road surface. As a result, it was utilised as an additional binder material to enhance the asphalt binder. The main purpose of this study is to investigate the stability of modified porous asphalt samples and evaluate the optimum percentage of HDPE plastic waste from 3%, 6% and 9%. The aggregates, asphalt properties, Marshall Parameters and water absorption test are in comply with JKR Standard and PWD 2008. At 3% of plastic addition has improved the stability of porous asphalt specimens. Adding plastic waste as a binder helps strengthen asphalt binding.

Keywords: Porous asphalt; Asphalt binder; HDPE plastic waste; Stability strength; Marshall properties

1. Introduction

A porous asphalt mixture is described as an asphalt mixed with proper gradation and meet the quality of aggregates that contains 20% of air voids. Water can travel vertically through the porous asphalt mixture because of the widespread air voids in the road surface [1]. Usage of porous asphalt provides various advantages such as with increased skid resistance, reduced water ponding, reduced glare, and complete improvement of road safety protection.

Unfortunately, porous asphalt is known for its low stability strength. Generally, porous asphalt road surface applied for low traffic loads and parking surfaces [12]. The inadequate stability causes large cost of maintenance and repair in short duration. Thus, the porous asphalt pavement minimal stability requires a good binding to give better support by increasing the strength of holding between aggregates and asphalt binder. Meanwhile, In Malaysia an average of 0.85 kg to 1.5 kg single use plastic is discarded for every day. According to a research, Malaysia created 0.94 million tons of plastic waste globally, making it one of the countries with worst plastic pollution. According to

2019 research conducted by the WWF, Malaysia has the largest annual plastic usage in the world averaging 16.87 kilogram per person [4-6]. Landfills are filled with more single-use plastic wastes lead to difficulty in recycling process. One of single-use plastics is high-density polyethylene (HDPE).

Here, uses of recycled high-density polyethylene (HDPE) plastic waste as an additional binder material for asphalt binder is a good option to improve its stability. This mixture combination will produce tightly holding aggregates and asphalt binder with more stability to handle the traffic loads [13]. The modified HDPE porous asphalt pavement enhance the sturdiness and hardness of asphalt binder mixture. Therefore, in this research the recycled HDPE plastic waste applied as an extra binder material for support the asphalt binder. Reusing the HDPE plastic build sustainability environment and usage of porous asphalt pavement in future.

A standard porous asphalt structure consists of porous asphalt course, choker course, reservoir course, filter fabric and soil subgrade. To make a good porous asphalt mixture the factors such as compaction temperature, aggregates gradation and mixing process is important. The porous asphalt road was

¹ UNIVERSITI MALAYSIA PERLIS (UNIMAP), FACULTY OF CIVIL ENGINEERING TECHNOLOGY, KOMPLEKS PUSAT PENGAJIAN JEJAWI 3, 02600 ARAU, PERLIS, MALAYSIA

² UNIVERSITI MALAYSIA PERLIS (UNIMAP), CENTRE OF EXCELLENCE GEOPOLYMER AND GREEN TECHNOLOGY, (CEGEOGTECH), 01000 PERLIS, MALAYSIA

³ UNIVERSITI MALAYSIA PERLIS (UNIMAP), FACULTY OF CHEMICAL ENGINEERING AND TECHNOLOGY, 01000 PERLIS, MALAYSIA

⁴ UNIVERSITI TUN HUSSEIN ONN, FACULTY OF ENGINEERING TECHNOLOGY, PAGO, JOHOR, MALAYSIA

⁵ CZĘSTOCHOWA UNIVERSITY OF TECHNOLOGY, FACULTY OF MECHANICAL ENGINEERING AND COMPUTER SCIENCE, DEPARTMENT OF MECHANICS AND FUNDAMENTALS OF MACHINERY DESIGN, 73 DĄBROWSKIEGO AV., 42-201 CZĘSTOCHOWA, POLAND

* Corresponding author: liyanasofri@unimap.edu.my



first launched in Malaysia was 1991 and it was built beside Jalan Cheras-Berang. In 1996, roughly 16 locations on North-South Federal Highway were resurfaced with porous asphalt pavement [5].

Malaysian urban road surfaces are well known for flexible asphalt pavement usage. The physical of flexible pavement is made up of asphalt binder course and fine aggregates that enable for the small amount of water movement. Furthermore, flexible pavement construction was primarily concerned with protecting the pavement from deterioration. When compared to porous asphalt pavement, the key advantage is that water flow of the surface drains through the top asphalt layer and absorb into soil. Porous asphalt pavement is well-known in road construction industry as a viable solution for dealing with sewage issues and stormwater. Floods were minimized by 50% to 70% by the adoption of porous asphalt pavement usage at vulnerable regions. Additionally, between 1999 to 2011, multiple studies findings revealed that the average runoff water decreased by 50% to 93% [8-9].

On other hand, high-density polyethylene plastic is thermoplastic polymer made from monomer ethylene. The number "2" is the HDPE plastic recycling identification code. Shower cream bottles, laundry detergent, kitchen liquid storage bottle and chemical storage container are all made of HDPE plastic [11]. It is excellent in temperature endurance, hardening and stiffening properties. Moreover, HDPE plastic is a cost effective and easily reusable plastic. The melting point of HDPE plastic is 120°C.

The poor stability strength in porous asphalt pavement demanded a use of an additional plastic materials to support the binding between aggregates and asphalt binder [11]. Since asphalt binder mix characteristics perform a useful part in constructing a durable pavement. In order to obtain increased durability, high stability and strength a sizable number of researchers have investigated asphalt modification. Many projects have already been investigated and academics have successfully used a variety of plastic waste products [13-14]. As a result, the addition of plastic content with asphalt binder mix have possibility to enhance the potential of porous asphalt binder mixtures. Aside from improved stability, the modified asphalt mixtures provide benefits such as long-lasting roadways, sustainable ecology and cost effective road construction [10]. Repurposing HDPE plastic waste into asphalt pavements helps to reduce the amount of HDPE plastic that end up in dumps.

According to Gawande et al., [2], natural aggregates blended with plastic content has high possibility to form durable road pavement construction. When the studies comparing the modified asphalt mix has greater binding properties. Adding plastic content into asphalt mixture resulting good compression and bending strength. Thus, HDPE plastic waste has melting temperature of 130-140°C, it can blend easily when porous asphalt specimen mixtures blended. Other than, polymers improve asphalt stiffness and cracking of pavement mix design. Plastomer is a material with rubber characteristics. Therefore, adding HDPE plastic into asphalt binder can give more plasticity and elasticity properties to asphalt binders by enhancing it.

Based on previous research who conducted studies based on porous asphalt pavement enhance the stability of asphalt mixtures by applying various percentage of recycled HDPE plastic wastes. The study has proved that at 4% of HDPE plastic waste addition enhanced the stability strength of asphalt binder by 61.1%. Additionally, the presence of HDPE plastic waste into asphalt binder causes physical properties changes. More the quantity of HDPE plastic addition, the harder asphalt mix changes showed in penetration values. Increases HDPE plastic addition results in more contamination of plastic content displaying higher specific gravity of bitumen experiment data.

This research paper is to analyses onto study the physical properties of modified HDPE asphalt binder, stability criteria of asphalt layer when the recycled HDPE plastic waste added into porous asphalt mixtures and determine the best proportion of recycled HDPE plastic waste addition between 3%, 6% and 9%. This research experiment performed on penetration test, softening test, specific gravity of bitumen test, Marshall Parameters, and water absorption test.

2. Experimental

2.1. Materials

Natural limestone aggregates obtained from Pen Industries Sdn Bhd, Perlis, Malaysia. Natural limestone size aggregates of 14 mm, 10 mm, 5 mm, 2.36 mm and quarry dust were involved in this experiment. The specific gravity and water absorption test were conducted two sections according to the coarse and fine aggregates size. The bulk specific gravity value of 14 mm, 10 mm and 5 mm was recorded 2.629. The water absorption experiment values is 0.248%, that is less than 2% of JKR standard requirement. Secondly, the fine aggregates with size range from 2.36 mm and 0.075 mm. The fine aggregate has specific gravity of 2.284. Whereas the water absorption test value is 0.201%, that is less than 2% of JKR standard requirement.

Filler is used Ordinary Portland Cement (OPC) supplied by Highway and Traffic Laboratory, Unicity Alam Campus. The filler has a specific gravity of 3.15. Asphalt grade 80/100 obtained from Pen Industries Sdn. Bhd. Recycled HDPE plastic waste collected at home once the usage was over. Let the HDPE plastic wash and dry for 2 days and shredded into 4.0 mm. Type of HDPE plastic waste chosen is opaque. The specific gravity of recycled HDPE plastic waste is 0.95.

2.2. Sample preparations

The shredded HDPE plastic waste mixed with asphalt binder mixture using wet process to conduct physical properties tests. The shredded HDPE plastic waste is assembled in 3%, 6% and 9% and added into mass of asphalt binder. A total of 300 g of asphalt is heated and melted pour into metal container and added up the shredded HDPE plastic waste according to percentage.

Stir continuously until the HDPE plastic waste blended fully. Fig. 1 shows a picture of wet process method.



Fig. 1. HDPE plastic waste added into melted asphalt binder (Wet Process)

Meanwhile, dry process method, where the shredded HDPE plastic waste will add into porous asphalt mixture to created HDPE porous asphalt sample. The aggregates will pre-heated in oven at 160°C for 4hours before being mixing. For standard porous asphalt sample the aggregate, filler and asphalt binder will mixed in one time. While, for HDPE porous asphalt sample take two rounds of mixing. At temperature 160°C, the aggregates, filler, and shredded HDPE plastic waste blended first round to



Fig. 2. HDPE plastic waste added into porous asphalt sample mixture (Dry Process)

give space for HDPE plastic mixing. Then, the asphalt binder pours into the mixture to second round mixing. Fig. 2 shows a picture of dry process method. The hot blended mixture will transfer to cylindrical mould and compacted top and bottom for 50 blows. About 1200 g and 63.5 mm HDPE porous asphalt sample will be produced. After 24 hours, the sample extracted from mould in cool temperature.

2.3. Methods

The American Society of Testing and Materials (ASTM), PWD Malaysia's Specification for Road Works and Jabatan Raya Kerja (JKR) standard, 2008 were selected for this research study. The mechanical and physical properties of natural limestone were performed according to Section 4.6.1 JKR/SPJ/2008. The mechanical properties of natural limestone determine by aggregate crushing value (ACV) test and aggregate impact value (AIV) test. Followed by physical properties of natural limestone is investigated by specific gravity and water absorption test AASHTO T 85 and ASTM C 127. The porous asphalt aggregate grading selection is accordance by PWD, 2008 [7].

The physical properties of asphalt mixture are tested by penetration index test, softening test and specific gravity of bitumen. Penetration index test accordance to ASTM D5-97 standard to evaluate the hardness level of asphalt mixture. Softening test performed according to ASTM D36-95 to determine the softness level achieved the specific temperature by asphalt mixture. Whereas specific gravity of bitumen used standard ASTM D70-97. The purpose of this test is to know the specific gravity and density of asphalt mixture.

A solid HDPE porous asphalt sample will undergo Marshall Parameter tests according to ASTM D 6927 standard [3]. Before proceed to Marshall test the HDPE porous asphalt sample will undergo bulk specific gravity test accordance by standard ASTM D 2726 to study the bulk density of the sample. Then uncompacted porous asphalt mixture will test for theoretical maximum specific gravity (TMD) accordance to ASTM D 2041-91. It will investigate the maximum specific gravity and density of uncompacted HDPE porous asphalt mixtures. After that, a HDPE porous asphalt sample will be placed in water bath for 30 minutes before carrying out Marshall and flow test. This both tests carried out in accordance with ASTM D 6927. Marshall stability testing will be conducting to determine the deformation, rutting and shear stress of specimens. The flow test will be performed in combination with stability test, in which vertical deformation explains the deformation and pressing on the sample. Marshall stability proceed loading of 50.8 mm/min until failure occurs. The air voids test accordance to ASTM D 3203. Air voids test such as void in total mix (VTM), void in mineral aggregate (VMA) and void filled with asphalt (VFA). Finally, Marshall Quotient (MQ) is calculated using the experimental data of stability and flow. According to ASTM C 127-59, the water absorption test performed to percentage of water absorbed by the specimens.

3. Results and discussions

The mechanical properties of natural limestone studied using aggregate crushing value (ACV) test and aggregate impact value (AIV) test. While the physical properties of natural limestone performed by specific gravity and water absorption test. The experimental data of aggregate crushing value (ACV) test is 19.10%. As a result, the ACV findings used are less than 30%, which is the minimum value provided by JKR standard. Secondly, the experiment result of the aggregate impact value (AIV) test is 12.97%. As a result, the AIV data outcome used are less than 25%, which is the minimum figure needed by JKR standard. Therefore, the natural limestone aggregates are suitable for us in road structure pavements. Moreover, the nominal aggregate size of 14 mm was sieved according to graph curve restrictions for this experiment. Fig. 3 shows the graph curve of porous asphalt aggregate grading used in this research.

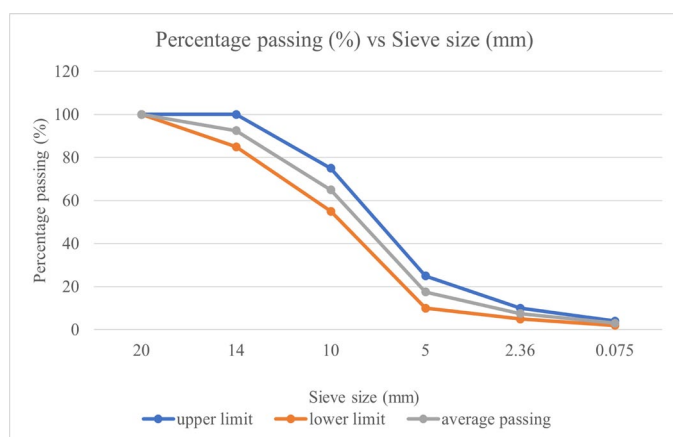


Fig. 3. Graph of porous asphalt sieve size grading and percentage passing

3.1. Physical properties test of asphalt mixture

The asphalt grade 80/100 was utilised in this study. Asphalt mixture is test on penetration, softening and specific gravity of bitumen tests. To study the influences of HDPE plastic in asphalt mixture the asphalt content without the presence of recycled HDPE plastic asphalt mixture is compared to the with presence of recycled HDPE plastic asphalt mixture. Wet process technique was applied in this experiment. TABLE 1 shows the experimental data of modified asphalt mixture after blended with HDPE plastic. When the amount of HDPE plastic waste added to the asphalt mix increased, showed the penetration value dropped

dramatically. The 0% of asphalt mixture was met the required criteria. While 3%, 6% and 9% asphalt mixture are not within the range of asphalt grade 80/100. The asphalt grade 80/100 has been associated with softer texture. Thus, after adding HDPE plastic waste, the penetration value recorded between 50 to 70 mm. As a result, the modified HDPE asphalt mixture being harder and thicker in texture. Therefore, the modified asphalt mixture showing enhanced sturdiness.

Softening test values went up when the addition of HDPE plastic increases. The 0% and 3% of HDPE asphalt mixture met the JKR standard criteria in 48.7°C and 51.2°C in temperature. While 6% and 9% of HDPE plastic added asphalt mixture temperature reaching are 53.9°C and 55.5°C, that is required higher heat capacity to achieve the softness level of asphalt.

Specific gravity of bitumen experiment presented significantly improved data when HDPE plastic addition increase together. HDPE asphalt mix such 0%, 3% and 6% met the JKR standard requirement with 1.037 g/cm³, 1.030 g/cm³ and 1.058 g/cm³ correspondingly. Meanwhile, 9% HDPE asphalt mix has 1.371 g/cm³ higher than requirement. Consequently, the higher specific gravity value shows that high HDPE plastic contents in asphalt mix does not suitable for road uses.

3.2. Marshall Parameters test

Marshall Parameters test such as stability, flow, void in total mix (VTM), void in mineral aggregates (VMA), void filled with asphalt (VFA) and Marshall Quotient (MQ) categories. A solid HDPE porous asphalt sample used to study the Marshall Parameters. The recorded experimental data must compare with JKR standard (2008). HDPE porous asphalt specimens performed on optimum asphalt content 5.5% by adding proportion of shredded HDPE plastic waste such 3%, 6% and 9%.

Fig. 4 shows a graph relationship between stability strength and percentage of HDPE plastic waste addition. The 3% HDPE porous asphalt specimens have the maximum stability values as seen in the graph. When compared to 0% HDPE porous asphalt specimens, there was a 73.71% of improvement in stability. Whereas the graph began to drop significantly at 6% and 9% HDPE porous asphalt specimens with 8014.33 N and 6438.33 N. All the HDPE porous asphalt specimens fulfil the minimum requirement stability which is 500 kg.

All sample flow test reading meets the JKR standard of 2-6 mm. the greatest flow value is 4.41 mm of 6% HDPE porous asphalt specimens. Whereas the 0% HDPE porous asphalt specimen is 2.43 mm, 3% HDPE porous asphalt specimen is

TABLE 1

Test results of asphalt grade 80/100 addition of HDPE plastic waste in various percentages such as 0%, 3%, 6% and 9%

Properties	JKR requirement	0%	3%	6%	9%
Penetration at 25°C (mm)	80-100	86.20	68.96	66.53	58.70
Softening point (°C)	42-52	48.70	51.20	53.90	55.50
Specific gravity at 25°C (g/cm ³)	1.01-1.05	1.039	1.030	1.058	1.371

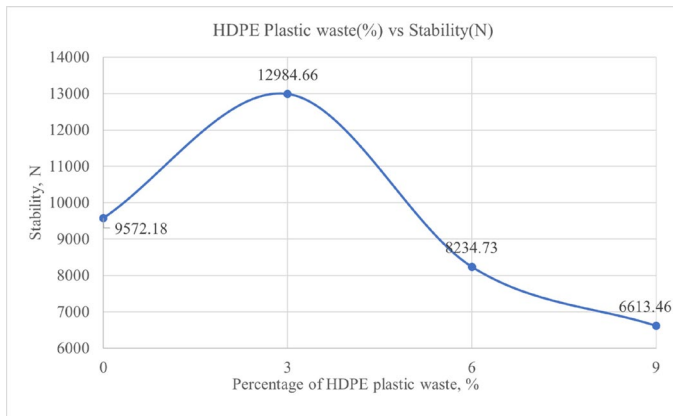


Fig. 4. Graph of stability and various percentage of HDPE plastic waste

2.78 mm and 9% HDPE porous asphalt specimen is 2.83 mm respectively. To ensure a stiffer asphalt mixture, the lowest value is necessary. The maximum flow value was chosen to ensure that asphalt mix is not too soft and thin [12]. All HDPE porous asphalt specimens flow values are between 2-6 mm. the addition of a higher percentage of HDPE plastic enhances the flow values while staying within the JKR criteria. In comparison to 9% HDPE porous asphalt specimens, the flow value of 6% HDPE porous asphalt specimen is greater. It shows that the 6% HDPE porous asphalt specimen is relatively soft and thin texture. Due to asphalt mixture has poor blending because of more quantity of shredded HDPE plastic added into specimen mixture produce harder sample having 2.83 mm flow value of 9% HDPE porous asphalt specimen. If the blending is satisfactory, the flow value of 9% HDPE porous asphalt specimen will be greater.

The 3% HDPE porous asphalt specimen has the greatest void in total mix (VTM) values, which is 17.72%. While the lowest value of VTM is recorded by 0% HDPE porous asphalt specimen, which is 15.98% and 6% and 9% HDPE porous asphalt specimen decreased little. With the plastic content, there was little modification in VTM results. The greater the value of VTM in the specimen, the better the ability of pavement to enable water to move though [12]. The VTM requirement value is 10%-25% are specified in JKR standard. The experimental data discovered between 10% to 25%.

According to the TABLE 2, raising the HDPE plastic content lowers the void in mineral aggregates (VMA) values of specimen. The 0% HDPE porous asphalt VMA is 19.05%. Following the 3% HDPE porous asphalt specimen has the higher VMA value, which is 19.70% since the addition of HDPE plastic

has been modified. While the rising of proportion of HDPE plastic addition of 6% and 9% was greatly reduced the VMA experimental data value by 11.62% and 10.73% respectively. The JKR standard does not specify any VMA limitation for asphalt mixtures. The addition of HDPE plastic was dramatically increased from 0% to 9% produce 105 to 20% of VMA experimental data. The greater the VMA, the higher area available for asphalt coating. The thick asphalt coverage good enough for produces a stable combination. Whereas more influence of HDPE plastic produces a thin asphalt coverage of aggregates has strength and stiffness difficulties.

TABLE 2 presented the void filled with asphalt (VFA) getting higher when the percentage of HDPE plastic addition in specimen mixture was increasing together. The 0% HDPE porous asphalt has 60.19% of VFA experimental value. After the addition of 3% of shredded HDPE plastic into specimen altered significantly increase the VFA result by 85.20%. The 6% and 9% HDPE porous asphalt specimen VFA value are 92.76% and 94.93% respectively. The JKR standard requirement is 75% to 85%. Therefore, the JKR standard was meet by HDPE porous asphalt specimens containing 0% and 3% of HDPE plastic. While 6% and 9% HDPE porous asphalt specimens were unable to fulfill the criteria because the experimental data exceeded 85%. As a result, the higher the VFA value displayed, the most soft and thin asphalt layer specimens cause the pavement bleed and crack easily. The greater the use of HDPE plastic content, the less suited for asphalt mixture blending.

The maximum Marshall Quotient (MQ) was recorded by 3% HDPE porous asphalt specimens, which is 4639.31 N/mm. The minimum MQ value is achieved by 6% HDPE porous asphalt specimen the experimental value is 1818.55 N/mm. Increasing the quantity of HDPE plastic pieces has an influence on the stability and flow. The greater the MQ value, the harder the specimen. While the lesser the MQ value, the more efficient the HDPE porous asphalt specimens. According to the MQ findings, 3% HDPE porous asphalt specimen had the more stability and low flow value. The maximum 3923 N/mm is the JKR standard requirement. As a result, all MQ values were within the acceptable range.

As a conclusion, 3% HDPE porous asphalt specimen was chosen as the best optimum percentage of recycled HDPE plastic waste for use as an additional plastic binder material for asphalt mixture. In comparison to 0%, 6% and 9% HDPE porous asphalt specimens, the 3% HDPE porous asphalt specimens met the JKR standard requirement in throughout all criteria with greatest

TABLE 2

Test results of Marshall Parameters of addition HDPE plastic waste in various percentages such as 0%, 3%, 6% and 9%

Properties	JKR requirement	0%	3%	6%	9%
Flow	2-6	2.43	2.78	4.41	2.83
Void in total mix (VTM)	10%-25%	15.98	17.72	17.14	17.05
Void in mineral aggregate (VMA)	—	19.05	19.70	11.62	10.73
Void filled with asphalt (VFA)	75%-85%	60.19	68.85	92.76	94.93
Marshall Quotient (MQ)	Maxi 400 kg/mm	3891.60	4639.31	1579.59	2275.53

TABLE 3

Test results of water absorption test of addition HDPE plastic waste in various percentages such as 0%, 3%, 6% and 9%

Percentage of HDPE plastic waste (%)	0%	3%	6%	9%
Duration immersed in water	Percentage of water absorption (%)			
2 Hours	0.25	0.22	0.16	0.23
24 Hours	0.44	0.57	0.28	0.24
48 Hours	0.59	0.67	0.30	0.24

test results. In other hand, 0% HDPE porous asphalt specimens met the criteria of Marshall Parameters but much lower than 3% HDPE porous asphalt specimen. However, the test results 6% and 9% HDPE porous asphalt ended in failure to VFA test plus the experimental data is lower than 0% and 3% OF HDPE porous asphalt specimens.

3.3. Water Absorption Test

Water absorption test performed for total 8 HDPE porous asphalt specimen, which is consists of 0%, 3%, 6% and 9% of shredded recycled HDPE plastic waste addition binder material in porous asphalt specimen mixtures. The duration took place by the water absorption test were 2 hours, 24 hours and 48 hours. TABLE 3 shows the experimental data of water absorption test.

In comparison, 0% and 3% HDPE porous asphalt specimens have more percentage of water absorption value, while 6% and 9% HDPE porous asphalt specimen have lower percentage of water absorption. In road pavement surface construction, the percentage of water absorption range is 0.1% to 2.0%. As a result, showed the percentage of water absorption experiment data of 2 hours, 24 hours and 48 hours were within the stated range. Anyhow, when the quantity of HDPE plastic waste in porous asphalt mixture increased cause the HDPE porous asphalt specimen percentage of water absorption is decreased. The higher the plastic content, the more asphalt mixture quantity in the HDPE porous asphalt make difficulty to water moisture to stay or pass through.

4. Conclusion

The increasing addition recycled HDPE plastic waste into asphalt mixtures shows changes in physical properties of asphalt. The most of the modified asphalt specimens met the required requirements. As the amount of HDPE plastic added increase, the penetration values drop. It is indicating that the modified asphalt mix become harder and denser. The softening results showed that thicker modified asphalt blend mixer needed a higher heat capacity to reach the specific softness level. Furthermore, the more the HDPE plastic waste was added to asphalt mix, the greater the specific gravity of bitumen.

The greatest Marshall stability strength of the 3% HDPE porous asphalt sample is 12888 N. The stability was improved

by 73.71% comparing with 0% HDPE porous asphalt sample. As a result, the more the proportion of HDPE plastic added, the lower the stability of the specimens. Hence, adding 3% shredded HDPE plastic into asphalt mixes enhances its performance and increases stability.

In comparison to 6% and 9% of HDPE porous asphalt specimens, 3% HDPE porous asphalt specimen fulfilled all Marshall Parameters with meets the criteria in better experimental data. While the JKR standard is met by 0%, 6% and 9% HDPE porous asphalt specimens fulfil the requirements but with lowest experimental data.

Acknowledgement

The authors acknowledge Faculty of Civil Engineering Technology and Centre of Excellence Geopolymer and Green Technology, (CEGeoGTech), Universiti Malaysia Perlis (UniMAP) for lab facilities. Special thanks to those who contributed to this project directly or indirectly.

REFERENCES

- [1] A.E. Alvarez, A.E. Martin, C.K. Estakhri, J.W. Button, C.J. Glover, S.H. Jung, Synthesis of current practice on the design, construction, and maintenance of porous friction courses (No. FHWA/TX-06/0-5262-1). (2006).
- [2] A. Gawande, G. Zamare, V.C. Renge, S. Tayde, G. Bharsakale, An overview on waste plastic utilization in asphaltting of roads. *Journal of Engineering Research and Studies* 3 (2), 1-5 (2012).
- [3] A. Astm, D6927-15 Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures. ASTM International: West Conshohocken, PA, USA. (2015).
- [4] H.L. Chen, T.K. Nath, S. Chong, V. Foo, C. Gibbins, A.M. Lechner, The plastic waste problem in Malaysia: management, recycling and disposal of local and global plastic waste. *SN Applied Sciences* 3 (4), 1-15 (2021).
- [5] N.A. Abdullah, H. Cheang, M.H. Harun, Single-Use Plastic: Reduce Or Ignore. *International Journal of Law, Government and Communication* 6 (26), 120-126 (2021).
- [6] D. Krishnan, M. Ghazali, K.M. Shahid, S.S.H. Hussaim, S. Hassan, Recycling Knowledge among Malaysians Towards Maintaining Clean Environment. *Journal of Tourism Hospitality and Environment Management* 7 (29), 336-343 (2022).
- [7] M.O. Hamzah, M.M. Samat, K.H. Joon, R. Muniandy, Tech, D., Bangwha2-dong, G.K. Modification of aggregate grading

- for porous asphalt. In Proceedings of the 3rd Eurasphaly and Eurobotume Congress, Vienna, Austria (**200**) (2004, May).
- [8] J.G. Speight, Handbook of petroleum refining. CRC press. (2016).
- [9] Z. Ghafari Frad, M. Khabiri, T.A. Kornel, Modification of Aggregate Gradation for Simultaneous Optimization of Evaporation and Permeability of Porous Asphalt Mixtures. (2022).
- [10] JKR/SPJ/-S4 (2008). Standard Specification for Road Works. Malaysian Public Works Department.
- [11] K. Kumar, S. Prasad, Porous asphalt pavement a texture mix design guideline by new generation open graded friction course approach. International Journal of Engineering Science Invention Research & Development, 105 (2014).
- [12] J. Lombardo, How porous asphalt pavements works for construction pros. Retrieved on June 15, 2021 (2020). from <http://www.forconstructionpros.com/asphalt/article/21134321>
- [13] K.M. Bilal, A. Sarfraz, I. Muhammad, M. Sajid, Comparative analysis of conventional and waste polyethylene modified bituminous mixes. In 2013 the International Conference on Remote Sensing, Environment and Transportation Engineering 344-347 (RSETE 2013). Atlantis Press.
- [14] E.E. Putri, O. Vasilisa, Improve the Marshall stability of porous asphalt pavement with HDPE addition. In MATEC Web of Conferences **276**, 03005 (2019). EDP Sciences.
- [15] E.E. Putri, M. Idral, J. Makinda, L. Gungat, Marshall properties of porous asphalt with gondorukem rubber addition. Journal of Engineering Science and Technology **14** (1), 167-180 (2019).
- [16] F. Mushtaq, Z. Huang, S.A.R. Shah, Y. Zhang, Y. Gao, M. Azab, S. Hussain, M.K. Anwar, Performance Optimization Approach of Polymer Modified Asphalt Mixtures with PET and PE Wastes. A Safety Study for Utilizing Eco-Friendly Circular Economy-Based SDGs Concepts (2022).
- [17] T. Yu, H. Zhang, Y. Wang, Interaction of asphalt and water between porous asphalt pavement voids with different aging stage and its significance to drainage. Construction and Building Materials **252**, 119085 (2020).