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LABORATORY CHARACTERIZATION OF MODIFIED POROUS ASPHALT WITH NANO CaCO3 AND BUTON GRANULAR ASPHALT (BGA)

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Abstract

The latest research that combines two natural materials, namely nano CaCO3 and Buton Granular Asphalt (BGA), aims to determine their effect on the performance of Porous Asphalt (AP) mixtures based on mechanistic updates. This study's characterization was carried out using the Particle Size Analyzer (PSA) and Scanning Electron Microscope (SEM) techniques. The results show that the CaCO3 nanomaterial has a very small particle size on the nanometer scale and has an orderly crystal structure. Nano CaCO3 can strengthen mixed bonds due to its excellent absorption properties. Furthermore, as a local material, BGA contains highly aromatic and resinous materials, which increase stiffness with sufficient flexibility limits to withstand traffic loads. 2% and 3% nano CaCO3 and 3% BGA were used as mixture variations. The performance of the mixture was evaluated by testing Marshall, Cantabro Loss, Asphalt Drain Down, Permeability, and Indirect Tensile Strength. The greatest increase occurred by adding 2% nano CaCO3 and 3% BGA by 17%. The results showed that adding nano CaCO3 and BGA with the right proportions could improve the performance of the AP mixture.

Keywords: Porous Asphalt. Nano CaCO3. BGA. Characterization

INTRODUCTION

Porous asphalt (AP) is an innovative road pavement technology allowing water to flow continuously through pores [1]. AP pavement has received great attention to improving driving safety because of its good drainage performance [2], which can effectively provide a higher level of safety, especially when it rains because aquaplaning does not occur [9]. AP differs from conventional asphalt because it has larger air voids, thickness, and aggregate size [3]. AP is a special asphalt with a cavity content of 18% or more [4], compared to conventional pavement, which only has 2-3% [5]; open-grade AP is specially designed with large cavities so that it can drain water from the surface of the pavement 1]. AP allows new precipitation and water runoff to flow through the pavement surface layer from the open gradation, and then water seeps into the soil below [6]. However, with larger pores than conventional pavements, porous asphalt pavements have lower asphalt mixture characteristic values [19]. Great chance of rutting [7], Reveling, drain down, or ejection of bitumen from the mix during conveying and spreading [8]; the main causes of raveling and rutting are temperature sensitivity and lack of asphalt adhesion, especially under repeated heavy loads from vehicles [4], and low stability which can reduce AP performance so that service life becomes shorter [9]. This study uses nano CaCO3

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and BGA to improve AP performance.

Nanotechnology is science and technology that controls substances, materials, and systems at the nanometer scale, resulting in new functions that have never existed [10]. Nanomaterials have one dimension less than 100 nm [11]. The importance of these materials was realized when researchers discovered that size could affect the physicochemical properties of a substance [12]. Nanomaterials can stabilize subgrade soils in pavements and make them more durable and less erosive [13]. Nanomaterials have a significant effect in increasing the binding properties of the mixture [14]. Several AP studies with nanomaterials say that asphalt mixtures modified with 5% nano CaCO3 have better rutting resistance [15]. The use of nano CaCO3 produces a fairly good value of resistance to rutting [16]. Using nano CaCO3 can increase the mixture's resistance at high temperatures through a diffusion-enhancing mechanism [17].

Similarly, [18] said the use of nano CaCO3 could increase the resistance of the mixture at high temperatures by testing the Dynamic Shear Rheometer (DSR) and testing the viscosity [18]. The presence of CaCO3 nanoparticles and their positive impact on the viscoelastic behavior of asphalt [16]. Adding CaCO3 nanomaterials can improve flexible pavements' stability, rutting resistance, fatigue resistance, and optical properties [13].

BGA is the result of natural asphalt processing found on Buton Island, Southeast Sulawesi Province, Indonesia [19]. The amount is very abundant, so the high need for imported oil asphalt can be reduced by using BGA effectively [20]. BGA is a type of buton widely used as a filler substitute and a binder [21]. Several studies using button asphalt have shown that asphalt products can improve the mechanical performance of the mixture [22-23]. Adding 2.5% BGA to the asphalt mixture produces a higher compressive load capacity than the mixture without BGA [24]. The mixture's resistance to permanent deformation also increases with the addition of semi-extracted asbuton content and the mixture's resistance to fatigue cracking [25]. Increasing the level of asphalt hardness will increase the damage resistance criterion, namely rutting [26]. The increased stiffness due to adding rock bitumen can affect the low-temperature crack resistance of asphalt composites [27]. Other studies have shown that adding BGA can improve the performance of asphalt mixtures at high temperatures [28].

METHODOLOGY

The series of research flows to be conducted was divided into several stages. The initial stage is identifying and formulating the problems that would be raised in the research, as well as determining the basic hypotheses of the research that would be conducted. The next stage, or **Phase I,** is preparing the material and testing each material's characteristics. **Phase II** is testing the porous asphalt mixture modified with BGA and nanoparticles. The modified asphalt would then be used to manufacture asphalt mixture specimens. **Phase III** is the advanced testing stage. This stage was conducted to determine the performance of the mixture in each predetermined proportion. **Phase IV** is analyzing the results of further testing and evaluating the initial hypothesis and the research results. The test was conducted at the Road Laboratory, Bandung Institute of Technology.

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Porous asphalt gradation specifications used the Japanese method. The Stability Test is an empirical parameter to measure the ability of the asphalt mixture to withstand deformation caused by a load based on the General Specifications for Roads and Bridges of Highways in 2018. Permeability is an empirical parameter to measure the ability of a porous asphalt mixture to flow water, which in this test refers to Falling Head Permeability (Pusjatan 2012). Cantabro Loss is an empirical parameter to measure the ability of a mixture to determine the bond between aggregate and asphalt (ASTM C-131), and Asphalt Drain Down is an empirical parameter to determine the amount of asphalt drain-down that occurs in asphalt mixtures that have not been compacted from production sites, transportation to the location (AASHTO T305-14)

METHODOLOGY

Characterization Nano CaCO3 Particle Size Testing (PSA)

CaCO3 nanomaterials are tested in particle sizes to ensure that the materials used are nano sized. The test was carried out by first mixing nano CaCO3 with distilled water until the dose was thin enough, then vibrating so that it was evenly mixed, and finally testing using Particle Size Analysis.

CaCo3_5626.nsz

Measurement Results

Date	: 09 November 2021 12:44:10
Measurement Type	: Particle Size
Sample Name	: CaCo3
Scattering Angle	: 90
Temperature of the Holder	: 25.0 deg. C
Dispersion Medium Viscosity	: 1.085 mPa.s
Transmission Intensity before Meas.	: 22590
Distribution Form	: |Standard|
Distribution Form(Dispersity)	: Polydisperse
Representation of Result	: Scattering Light Intensity
Count Rate	: 713 kCPS

Calculation Results

Peak No.	S.P.Area Ratio	Mean	S. D.	Mode
1	1.00	116.2 nm	26.0 nm	111.8 nm
2	---	--- nm	--- nm	--- nm
3	---	--- nm	--- nm	--- nm
Total	1.00	116.2 nm	26.0 nm	111.8 nm

Cumulant Operations

Z-Average	: 107.6 nm
PI	: 0.186

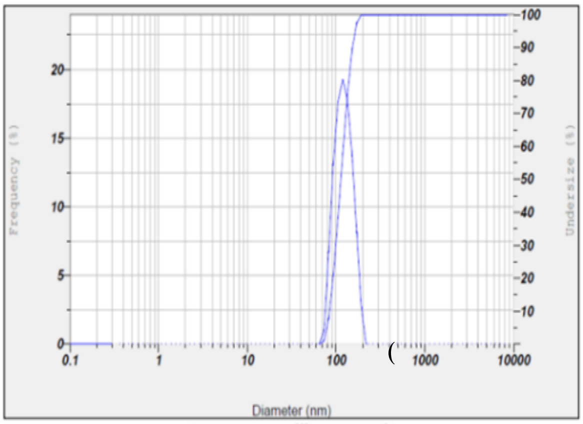

Fig 1: a. Measure Results and b. Chat Range of Nano CaCO3 values

Tests were carried out using a PSA tool and produced particle sizes of 116.2 ± 26 nm where the range of nanomaterial values ranged from 1-100 nm.

Characterization Nano Scanning Electron Microscopy (SEM)

SEM nano analysis is used to examine the physical properties and composition of materials at the nanometer scale which provides detailed information about the surface morphology of the sample as well as the identification of elements.

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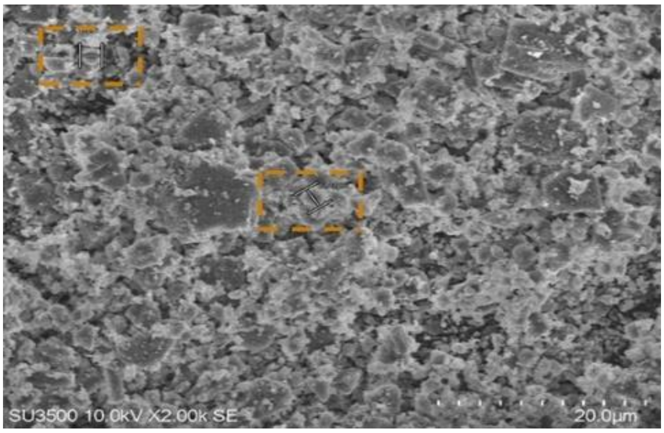

Figure 2: SEM Results Nano CaCO3.

SEM image (**Figure**. 3) reveals the details of the surface and topography of the sample average of imperfectly spherical, oval, and irregularly shaped particles of several small sizes.

Marshall Test

Specimens in the mold were allowed to cool to room temperature for 24 hours, then removed from the mold using a mechanical jack [29], then various tests were carried out to determine their strength, stability, and flow characteristics. This test helps in assessing the suitability of asphalt mixtures for road construction.

Permeability Test

The permeability value itself is a comparison of the height of the water passing through the test object for a long time. The permeability value can be calculated using the following formula [33]:

$$K=2{,}3\frac{aL}{At} \times [\log (\frac{h1}{h2})] \qquad (1)$$

Where:

k = Coefficient of water permeability (cm/s)

L = Specimen thickness (cm)

a = Specimen sectional area (cm2)

A = Cut area of the test specimen

t = Time needed to drain water from h1 to h2 (s)

h1 = Height of the upper limit of water on the tube (cm)

h2 = Height of the bottom water level on the tube (cm)

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Contabo Loss Test

Then the samples were weighed and put into a Los Angeles machine without iron balls, rotated 300 revolutions at speeds ranging from 188 to 208 rad/s. According to the specifications, the CAL value is < 20%. Using the equation below and ASTM C-131 as a reference, the CAL value can be calculated as shown below [32]:

$$CAL = \frac{m2}{m1} \text{ x } 100\% \quad (2)$$

Where:
m1 = tray weight (gram)

m2 = The weight of the test object after rotating 300 revolutions. (gram)

Asphalt Drain Down

For the purposes of this test method, material flow-down is considered to be that part of the material which dissociates from the sample as a whole and is stored outside the wire basket during the test. The flow-down material may consist of an asphalt binder or a combination of asphalt binder and fine aggregate.

To determine the AFD value, the Asphalt Flow Down flow test was conducted using the equation below, referring to AASHTO T 305 as follows [31]:

$$AFD = \frac{m3 - m1}{m2 - m2} \text{ x } 100\% \quad (3)$$

Where
m1 = tray weight (gram)

m2 = the weight of the mold along with the asphalt mixture before being baked (gram)

m3 = the weight of the mold along with the asphalt mixture after being baked (gram)

Indirect Tensile Strenght (ITS)

This test is carried out to provide an indication of the mechanical performance of the mixture and evaluate its susceptibility to moisture [35]. Due to the porous nature of the PA specimens, it is not possible to record the saturation level required by typical testing procedures with the AASHTO T283 standard [36].

The minimum value for the TSR of the PA mix differs according to the requirements of the road authority, but usually, the required TSR value is greater than or equal to 90% [34].

RESULTS AND DISCUSSION

Based on the tests that have been carried out on each type of mixture, the following results are obtained:

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Buton Granular Asphalt (BGA)

Testing for BGA type B 5/20 was carried out in accordance with the requirements of the 2018 Revision 2 of the General Highway Specifications [29]. The sieve analysis test took samples weighing 500 grams each four times.

Table 1: Buton Granular Asphalt test results

No	Properties	Standards	Specification	Value
1	**Bitumen Gread (%)**	SNI 03-4142-1996	18-22	21,6
2	**Water Content (%)**	SNI 03-4142-1996	Max 4	0,83
3	**Flash Point (^{0}C)**	SNI 03-2433-1991	-	2,83
4	**Penetration (dmm)**	SNI 03-2456-2011	<15	12
5	**Passed Sieve No.8 (%)**	SNI 03-4142-1996	100	100
6	**Asbuton Grain Size (inch)**	SNI 03-4142-1996	Max 8	8
7	**Spesific Gravity**	SNI 03-2441-2011	-	1,054

All tests carried out on Buton Granular Asphalt have met the requirements set.

Table 2: Recapitulation of the results of testing variations of porous asphalt mixtures

			Mixtures Variations				
Specification	**Value**	**1**	**2****	**3**	**4**	**5***	**6**
Stabilities Marshall	> 500	500,35	699,97	530,41	605,10	842,70	567,49
Void in Moisture	15- 25 %	17,221	16,48	15,39	16,62	16,60	14,38
Cantabro Loss	< 20%	15,29	8,12	11,01	10,96	7,50	10,10
Asphalt Draindown	< 0,3%	0,480	0,140	0,250	0,10	0,130	0,11
Permeability	>0,01	0,093	0,091	0,089	0,090	0,090	0,081
Indirect Tensile Strenght	Min 90%	90,09	94,22%	91,72	95,47	95,28	93,77

Mixed Type Information:

1. (AP1) Kontrol
2. (AP2) Modified Porous Asphalt with nano CaCO3 2%**
3. (AP3) Modified Porous Asphalt with nano CaCO3 3%
4. (AP4) Modified Porous Asphalt with BGA 3%
5. AP5) Modified Porous Asphalt with nano CaCO3 2% + BGA 3%*
6. (AP6) Modified Porous Asphalt with nano CaCO3 3% + BGA 3%

Based on the Marshall Stability value of nine modifications of Porous Asphalt with 2% nano CaCO3 and 3% BGA (AP5) the highest stability value was 842.70 kg.

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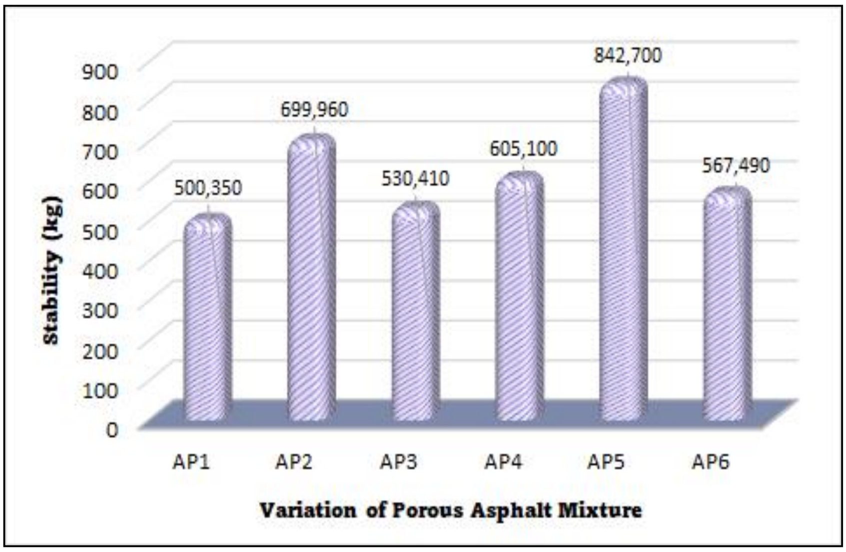

Fig 3: Chat Marshall Stability (kg)

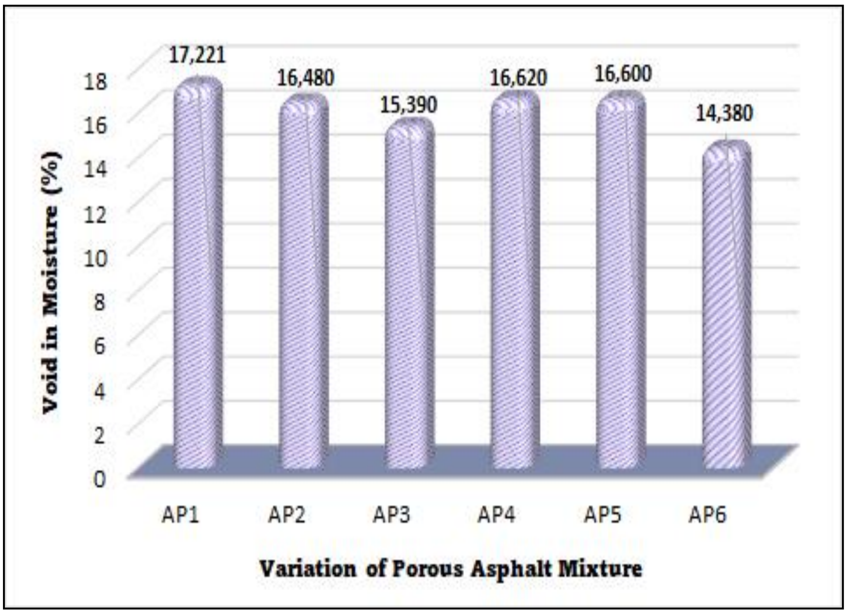

Fig 4: Chat Void in Moisture (%)

The magnitude of the stability value is influenced by the frictional resistance and interlocking that occurs between the aggregate particles and the cohesion of the mixture (Figure 3). The cohesive strength increases with the increase in the amount of asphalt covering the aggregate, the asphalt content contained in BGA. The nano $CaCO_3$ is able to absorb into the mixture so as to provide good adhesion to the mixture and maintain the mixed condition of the contact pressure between the aggregates.

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From the analysis results, the addition of BGA with nano materials will make the VIM value smaller (Figure 4). The decrease in the VIM value occurs due to the increasing amount of asphalt that fills the voids in the mixture so that the remaining voids or air voids in the mixture are getting smaller. The lower the VIM value, the higher the risk of the mixture experiencing bleeding and the higher the risk of the mixture experiencing a decrease in durability. It can be concluded that a mixture that does not meet the VIM value according to specifications, namely 15% - 25% is the addition of 3% BGA with 3% nano CaCO3 and 3% BGA with 3% nano CaCO3.

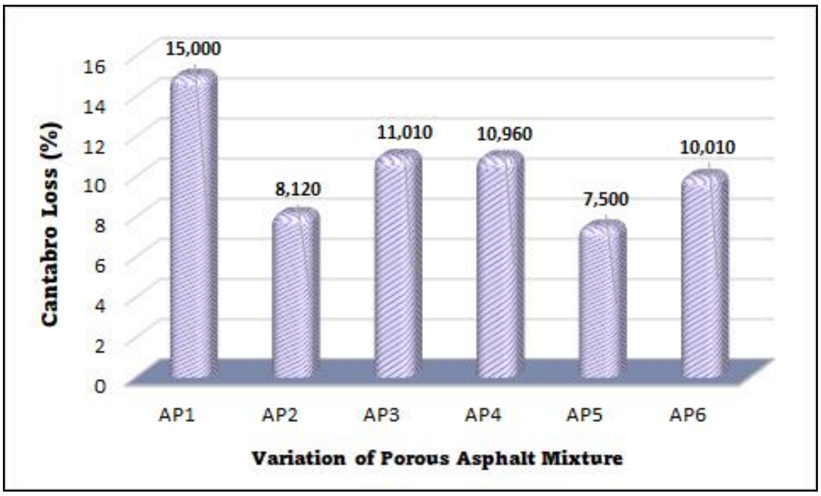

Fig 5: Cantabro Loss

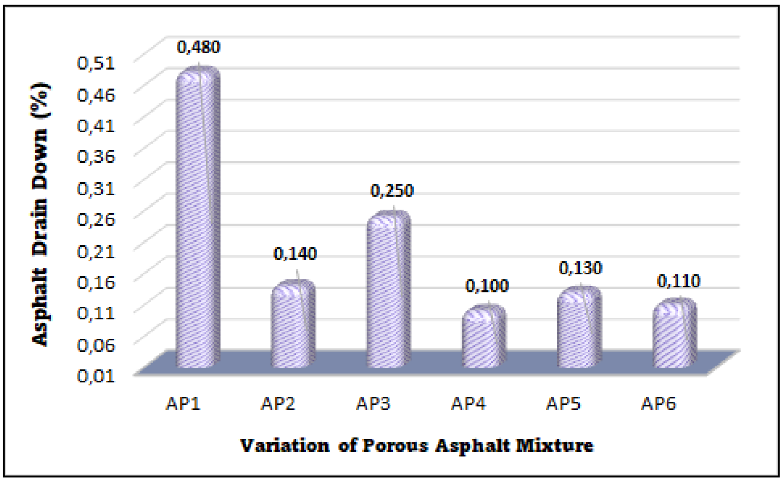

Fig 6: Asphalt Drain Down

The Cantabro Loss test is carried out to show the resistance of a test object to friction or abrasion pressure. The smaller the weight loss that occurs in the test object, the more resistant the test object is to friction or abrasion, (Figure 5). The use of 2% nano CaCO3 and 3% BGA in a porous asphalt mixture shows less weight loss than other mixture variations as shown in

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Figure 10 above. This really proves that the ability of nano CaCO3 is very good in terms of binding and also retaining fish between mixtures. It can also be said that the capabilities of the two materials are also quite good. The addition of bitumen content in each material can reduce the abrasion value and increase the bond between aggregates.

From **Figure. 6** above, it can be seen that the addition of CaCO3 nanomaterials is able to strengthen mixed bonds. This is due to the absorption properties of nanomaterials which can reduce asphalt degradation in the mixture. The addition of BGA to porous asphalt mixtures can also be seen to have a good effect as indicated by the results which are required, namely < 0.3% for each addition of bitumen content, meaning that the effect of BGA also provides a good bond so that the decrease in asphalt is smaller. aggregate binding and enveloping ability are quite good.

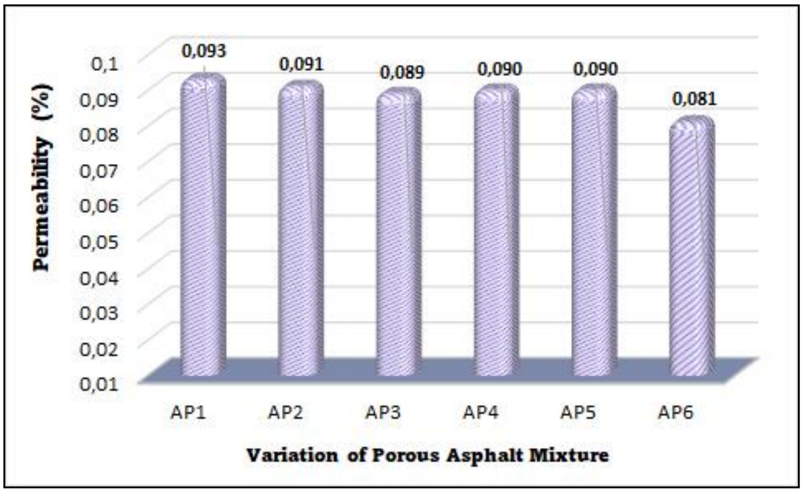

Fig 7: Permeability

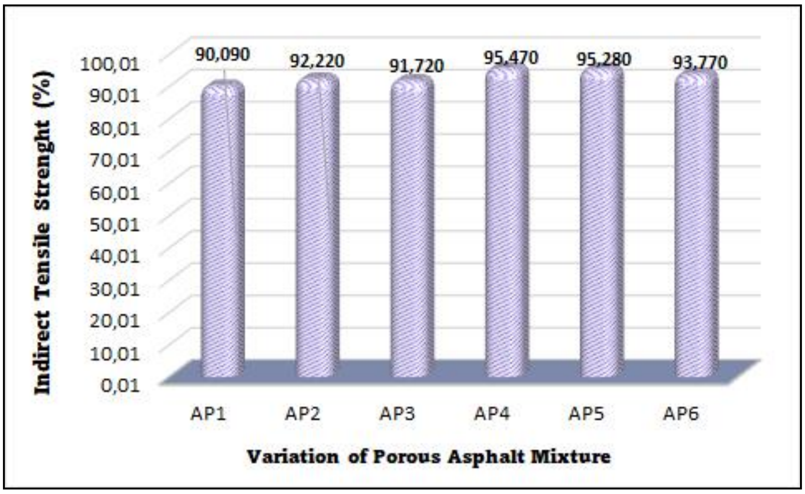

Fig 8: Indirect Tensile Strength

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Figure. 7 below shows that the mixture without added ingredients has a higher permeability because the test object has a cavity or a higher VIM percentage than the other mixtures, namely 17.221%, while the lowest permeability is a mixture with Modified Porous Asphalt with 3% nano CaCO3 3% and BGA 3%

Adding BGA and nano CaCO3 increased the percentage of fine aggregate, which resulted in reduced voids. This reduction in cavities will, of course, be related to the ability of the mixture to drain water. By taking this into account, it can be seen that the addition of additives, especially BGA and nano CaCO3 improves the performance of the porous asphalt mixture without significantly reducing its ability to drain water from the pavement structure.

Indirect Tensile Strength is a measure of the ability of an asphalt mixture to withstand the tensile forces that occur on a pavement. This parameter is also related to resistance to cracking due to temperature and shrinkage (Thermal and Shrinkage Cracking resistance). Figure 8

As for nano CaCO3 in a porous asphalt mixture, it can also increase the stiffness modulus value; it can be seen with the second highest ratio level, the addition of 2% CaCO3 to a porous asphalt mixture with 3% BGA can improve the characteristics of the mixture, nano CaCO3 contributes to an increase in cohesive properties so that the mixture can maintain aggregate.

CONCLUSION

The results obtained in this study show that adding nano CacO3 and BGA with the right percentage is very promising as an additive that can improve the performance of AP mixtures. The six variations show that adding 2% nano CaCO3 and 3% BGA increases the Stability value by 17%, and resistance to frictional stress measured by Cantabro Loss is also getting smaller. The addition of this material can also provide resistance to cracking due to temperature and shrinkage of porous asphalt mixtures with a ratio of 95.280%. Still, adding nanomaterials CaCO3 and BGA reduces the permeability of the mixture. This is likely affected by additional materials covering the cavity, but this value does not significantly reduce its ability to drain water from the pavement structure. The addition of CaCO3 nanomaterials can strengthen the bonds of the mixture due to the absorption properties of nanomaterials that can minimize the decrease of asphalt in the mixture. Likewise, the influence of BGA also provides good bonding so that the asphalt drop is smaller. So adding nano CaCO3 and BGA materials with the right percentage can improve the performance of porous asphalt mixtures.

References

1) Al-Jumaili MA. Laboratory evaluation of modified porous asphalt mixtures. Appl. Res. J.; 8:2-3. (2016)

2) Nguyen TH, Ahn J, Lee J, Kim JH. Dynamic modulus of porous asphalt and the effect of moisture conditioning. Materials. 15;12(8):1230.(2019)

3) Hernandez-Saenz MA, Caro S, Arámbula-Mercado E, Martin AE. Mix design, performance and maintenance of Permeable Friction Courses (PFC) in the United States: State of the Art. Construction and Building Materials. 2016 May 15; 111:358-67..

4) Zhang, H., Li, H., Zhang, Y., Wang, D., Harvey, J., & Wang, H. Performance enhancement of porous asphalt pavement using red mud as an alternative filler. Construction and building materials, 160, 707-713. (2018)

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.8311055

5) Ahmad, Kabiru Abdullahi, Mohd Ezree Abdullah, Norhidayah Abdul Hassan, Hussaini Ahmad Daura, and Kamarudin Ambak. "A review of using porous asphalt pavement as an alternative to conventional pavement in stormwater treatment." World Journal of Engineering 14, no. 5 (2017): 355-362.

6) Chen, J. S., & Yang, C. H. Porous asphalt concrete: A review of design, construction, performance, and maintenance. International Journal of Pavement Research and Technology, 13, 601-612. (2020).

7) Nekkanti, Haripriya, Bradley J. Putman, and Behrooz Danish. "Influence of aggregate gradation and nominal maximum aggregate size on the performance properties of OGFC mixtures." Transportation Research Record 2673, no. 1 (2019): 240-245.

8) Watson, Donald, Jason Moore, and Fan Gu. Evaluation of the benefits of open-graded friction course (OGFC) on NDOT Category-3 Roadways. No. 557-13-803. Nevada. Dept. of Transportation, 2018.

9) Falderika, Falderika. Evaluation of Resilient Modulus and Permanent Deformation of Porous Pen 60/70 Asphalt Mixture with Buton Natural Asphalt (BNA) Additives. (2017).

10) Laurent, B. (2011). “Democracies on trial: Assembling nanotechnology and its problems”. (Doctoral dissertation, École Nationale Supérieure des Mines de Paris).

11) Tiwari, J. N., Tiwari, R. N., & Kim, K. S. (2012). “Progress in Materials Science Three-Dimensional Nanostructured Materials for Advanced Electrochemical Energy “devices. Prog. Mater. Sci, 57(4), 724-803.

12) Khan, Ibrahim, Khalid Saeed, and Idrees Khan. "Nanoparticles: Properties, applications, and toxicities." Arabian Journal of chemistry 12, no. 7 (2019): 908-931.

13) Zeng, Ling, Jie Liu, Qian-Feng Gao, and Hanbing Bian. "Evolution characteristics of the cracks in the completely disintegrated carbonaceous mudstone subjected to cyclic wetting and drying." Advances in Civil Engineering 2019 (2019).

14) Saltan, Mehmet, Serdal Terzi, and Sebnem Karahancer. "Performance analysis of nano modified bitumen and hot mix asphalt." Construction and Building Materials 173 (2018): 228-237.

15) Zhai, Ruixin, Lingbo Ge, and Yu Li. "The effect of nano-CaCO3/styrene–butadiene rubber (SBR) on a fundamental characteristic of hot mix asphalt." Road Materials and Pavement Design 21, no. 4 (2020): 1006-1026.

16) Yarahmadi, Amir Mohammad, Gholamali Shafabakhsh, and Adel Asakereh. "Laboratory investigation of the effect of nano Caco3 on rutting and fatigue of stone mastic asphalt mixtures." Construction and Building Materials 317 (2022): 126127.

17) Yang, Yongpeng, Xiangjian Shen, and Yi-Fan Han. "Diffusion mechanisms of metal atoms in PdAu bimetallic catalyst under CO atmosphere based on ab initio molecular dynamics." Applied Surface Science 483 (2019): 991-1005.

18) Ali, Shaban Ismael Albrka, Amiruddin Ismail, Ramez A. AlMansob, and Dhawo Ibrahim Alhmali. "Evaluation of elevated temperature properties of asphalt cement modified with aluminum oxide and calcium carbonate nanoparticles." In IOP Conference Series: Materials Science and Engineering, vol. 236, no. 1, p. 012008. IOP Publishing, 2017.

19) Nabilla, Febby Salsha, Sofyan M. Saleh, and Cut Mutiawati. "Karakteristik Campuran Aspal Porus Dengan Buton Granular Asphalt Sebagai Bahan Substitusi Agregat Halus Dan Styrofoam Substitusi Aspal Pen 60/70." Journal of the Civil Engineering Student 2, no. 1 (2020): 92-98.

20) Tjaronge, M. W., S. A. Adisasmita, and M. Hustim. "Effect of Buton Granular Asphalt (BGA) on compressive stress-strain behavior of asphalt emulsion mixture." In IOP Conference Series: Materials Science and Engineering, vol. 271, no. 1, p. 012069. IOP Publishing, 2017.

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.8311055

21) Zhong, Ke, Xu Yang, and Sang Luo. "Performance evaluation of petroleum bitumen binders and mixtures modified by natural rock asphalt from Xinjiang China." Construction and Building Materials 154 (2017): 623-631.

22) Mahyuddin, Abrar, M. W. Tjaronge, Nur Ali, and M. Isran Ramli. "Experimental analysis on stability and indirect tensile strength in asphalt emulsion mixture containing buton granular asphalt." International Journal of Applied Engineering Research 12, no. 12 (2017): 3162-3169.

23) Tjaronge, M. W., Rita Irmawaty, and Muralia Hustim. "Effect of buton granular asphalt gradation and cement as filler on the performance of cold Mix asphalt using limestone aggregate." Journal of Engineering Science and Technology 15, no. 1 (2020): 493-507.

24) Tjaronge, M. W., S. A. Adisasmita, and M. Hustim. "Effect of Buton Granular Asphalt (BGA) on compressive stress-strain behavior of asphalt emulsion mixture." In IOP Conference Series: Materials Science and Engineering, vol. 271, no. 1, p. 012069. IOP Publishing, 2017.

25) Sentosa, Leo, S. Subagio Bambang, Harmein Rahman, and R. Anwar Yamin. "Warm mix asphalt mixture using modified asbuton semi extraction modify and synthetic zeolite additive." In MATEC Web of Conferences, vol. 276, p. 03003. EDP Sciences, 2019.

26) Indriyati, Eva Wahyu, Bambang Sugeng Subagio, and Harmein Rahman. "Improvement of Rheological Properties of Asphalt with the Addition of Pure Asbuton in Review of Stiffness Modulus and Pavement Damage Criteria." Dinamika Rekayasa 11, no. 2 (2015): 67-77.

27) Zhong, Ke, Xu Yang, and Sang Luo. "Performance evaluation of petroleum bitumen binders and mixtures modified by natural rock asphalt from Xinjiang China." Construction and Building Materials 154 (2017): 623-631.

28) Sihombing, Atmy Verani Rouly, Bambang Sugeng Subagio, Eri Susanto Hariyadi, and Anwar Yamin. "Chemical, morphological, and high-temperature rheological behavior of Bioasbuton as an alternative binder for asphalt concrete in Indonesia." Journal of King Saud University-Engineering Sciences 33, no. 5 (2021): 308-317.

29) Al-Jumaili, Mohammed Abbas Hasan. "Laboratory evaluation of modified porous asphalt mixtures." Appl. Res. J 8 (2016): 2-3.

30) Standard National of Indonesia. Standard Test Method of Asphalt Mix with Marshall Test. RSNI M- 01-2003

31) AASHTO T305-14. (2018). Standard Method of Test for Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures.

32) ASTM C-131. (2006). Standard Test Method for Resistance To Degradation Of Small-Size Coarse Aggregate By Abrasion And Impact In The Los Angeles Machine

33) ASTM Standards ASTM D4867 Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures

34) Lyons, Kimberly R., and Bradley J. Putman. "Laboratory evaluation of stabilizing methods