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Innovative Modifications in Porous Asphalt: The Role of Nano CaCO3 and Buton Granular Asphalt in Enhancing Porosity and Strength

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ABSTRACT
Calcium carbonate (CaCO3) nanomaterials have become a major focus in materials research today due to their unique properties and potential applications in various fields of science, one of which is road pavement. In this study, characterization and study of the potential application of CaCO3 nanomaterials in porous asphalt pavement technology (AP) were carried out. Characterization is carried out through Particle Size Analyer (PSA) and Scanning Electron Microscope (SEM) analysis techniques. The results showed that the CaCO3 nanomaterial has a very small particle size on the nanometer scale and has a regular crystal structure. Furthermore, utilizing Buton Granular Asphalt (BGA) as a local material known to contain aromatic ingredients and high resins serves to increase stiffness with sufficient flexibility limits to withstand traffic loads. The use of nano CaCO3 with variations of 0%, 2% and 3% while for BGA 3% and 4%. This is the first study to combine the two materials. Mixture performance is evaluated through Marshall, Cantabro Loss, Asphalt Drain Down, Permeability and Indirect Tensile Strength tests. The aim is to determine the effect of the use of BGA and also nano CaCO3 on mixed performance based on mechanistic reviews and can improve quality and contribute to sustainable technology development

KEYWORDS: *Porous Asphalt, Nano CaCO3, BGA, Porosity, Strength.*

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I. INTRODUCTION

Porous Asphalt (AP) is an innovative road pavement technology, which allows water to flow through the pore continuously [1]. AP pavement has received great attention for improving safety in driving because of its good drainage performance [2], it can effectively provide a higher level of safety especially in rainy times because aquaplaning does not occur [9]. AP differs from conventional asphalt because it has a larger air cavity, 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 graded AP specially designed with a large cavity so that it can drain water from the pavement surface [1]. AP allows new precipitation and water runoff to flow through the surface layer of pavement from its exposed gradation, then water seeps into the ground below [6]. However, with larger pores than conventional pavements, porous asphalt pavements have lower asphalt mixture characteristic values [19]. The chances of large rutting [7], Reveling, draindown or asphalt exit from the mixture during transportation and laying [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 also low stability which can degrade AP performance resulting in shorter service life [9]. In this study using nano CaCO3 and BGA as one of the efforts to improve AP performance.

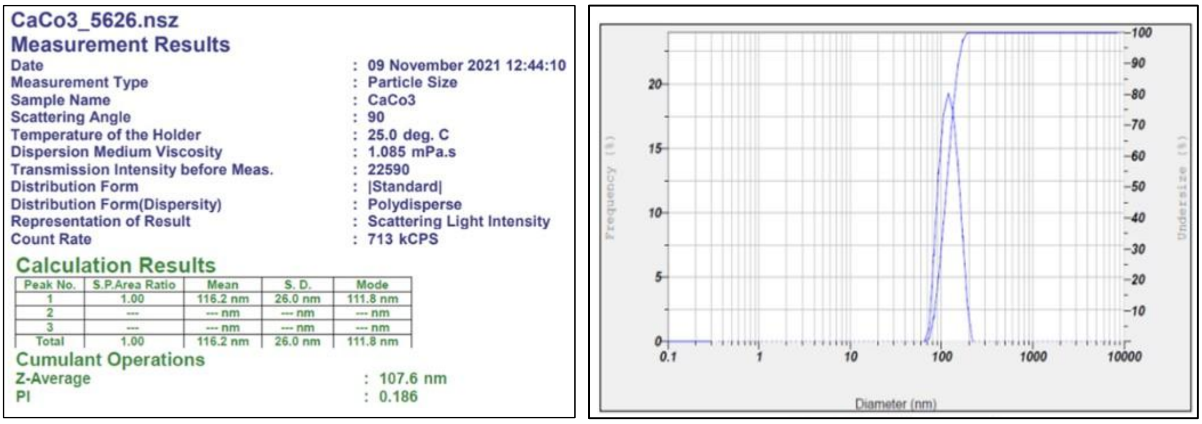
Nanotechnology is the science and technology that controls substances, materials and systems at the nanometer scale, resulting in new functions that have never existed [10]. Nanomaterials have one dimension less than 100 nm [11]. The importance of these materials was realized when researchers discovered that size can affect the physical-chemical properties of a substance [12]. In pavement, nanomaterials can stabilize the base soil and make it more durable and less erosive [13]. Nanomaterials have an effect significance in improving the binding properties of mixtures [14]. Some AP studies with nanomaterials say that, Campuran aspal yang dimodifikasi 5% nano CaCO3 memiliki ketahanan rutting yang lebih baik [15]. The use of nano CaCO3 produces a fairly good rutting resistance value [16]. The use of nano CaCO3 can increase the resistance of mixtures at high temperatures through a diffusion enhancing mechanism [17]. Similarly to [18] said the use of nano CaCO3 can increase the resistance of mixtures at high temperatures which is with Dynamic Shear Rheometer (DSR) testing and viscosity testing [18]. The existence of Nano CaCO3 particles and their positive impact on the viscoelastic behavior of asphalt [16]. The addition of CaCO3 nanomaterials can improve stability, rutting resistance, fatigue resistance, and optical properties of flexible pavements [13].

BGA is the result of natural asphalt processing found on Buton Island, Southeast Sulawesi Province-Indonesia [19]. The amount is so abundant that the need for imported oil bitumen is very high can be reduced through the effective use of BGA [20]. BGA is one type of asbuton that has been widely used as a substitute for fillers, as well as a binder [21]. Several studies using buton asphalt show that asphalt products can improve the mechanical performance of mixtures [22-23]. The addition of 2.5% BGA to the asphalt mixture results in a higher compressive load capacity compared to the mixture without BGA [24]. The resistance of the mixture to permanent deformation is also increased with the addition of semi-extraction asbuton content and the resistance of the mixture to fatigue cracking [25]. The addition of Pure Asbuton to the 60/70 asphalt pen increases the hardness of the asphalt. An increase in the hardness level of asphalt will result in an increase in the criterion of resistance to damage, namely rutting [26]. Increased stiffness due to the addition of rock bitumen can affect the low-temperature cracking resistance of asphalt composites [27]. Other studies have shown that the addition of BGA can improve the performance of asphalt mixtures at high temperatures [28].

II. EXPERIMENTAL

Characterization Nano CaCO3 Particle Size Testing (PSA)

CaCO3 nanomaterials are tested in particle size to ensure that the material used is nano-sized. The test was carried out by first mixing nano CaCO3 with distilled water until the dose was thin enough then vibrated to mix evenly and finally tested using Particle Size Analysis. The test was carried out using the PSA tool and produced particles of 116. 2 ± 26 nm size where the range of nanomaterial values ranged from 1-100.



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

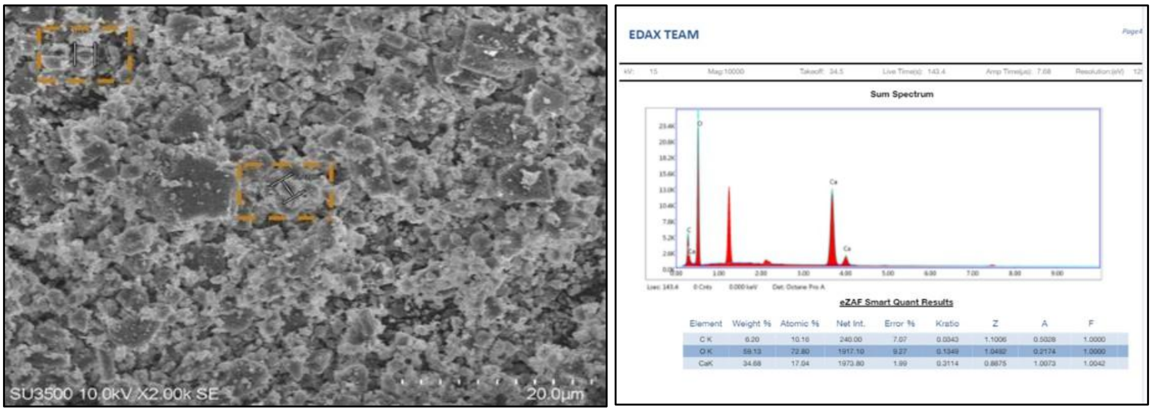
Cumulant Operations

Z-Average : 107.6 nm
PI : 0.186

Figure 2.1. Measure Results (A**)** And graph Range of Nano CaCO3

Characterization Nano CaCO3 Scanning Electron Microscope (SEM-EDS)

Setelah perlakuan material nano CaCO3, selanjutnya dilakukan pengecekan ukuran partikel menggunakan Scanning of Electron Microscopy Equipment (SEM) and obtained results of fly ash have been reduced from 20 µm to 200 nm.



eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	A	F
C K	6.20	10.16	240.00	7.07	0.0343	1.1006	0.5028	1.0000
O K	59.13	72.80	1917.10	9.27	0.1349	1.0492	0.2174	1.0000
CaK	34.68	17.04	1973.80	1.99	0.3114	0.8675	1.0073	1.0042

Figure 2.2. SEM Results and Graph of Mineral Elements in Nano CaCO3

Buton Granular Asphalt (BGA)

BGA type B 5/20 testing was conducted in accordance with the requirements of the General Highway Specification Revision 2 of 2018 [29]. Sieve analysis testing takes samples weighing 500 grams each four times.

Table 1: Product Specification Buton Granular Asphalt

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

Marshall Test

Marshall testing is carried out by immersing the specimen for 30 minutes at 60°C then testing its strength with a Marshall machine. This test is performed to obtain the stability and porosity level (VIM) values of each mixture combination

Permeability Test

This test is carried out by placing the test specimen on a permeability measuring device then irrigated with water. After that, the time it takes for water to flow from one point to the next is measured and then the permeability coefficient is calculated. The purpose of this test is to determine the ability of the specimen to absorb water. The permeability value itself is a comparison of the level of water through the test object for a long time. The permeability value can be calculated by the following formula Using **Equation 1** [32]:

$$\mathbf{k=2,3\frac{al}{At}\ x\ [\log(\frac{h1}{h2})]} \qquad (1)$$

Where:

k = Coefficient of water permeability (cm/s) L = Specimen thickness (cm)

A = Specimen sectional area (cm2)

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)

Cantabro Loss Test (CL)

Before testing, the specimen was stored at 25°C for six hours, then the sample was weighed and fed into a Los Angeles machine without an iron ball, rotated 300 revolutions at speeds ranging from 188 to 208 rad/s. According to the specifications, the CL value is 20%. Using **Equation 2** and ASTM C-131 as a reference, typical values of Cantabro losses can be calculated as shown below [31]

$$\mathbf{CL} = \frac{\mathbf{m2}}{\mathbf{m1}}\ \mathbf{x\ 100\%} \qquad (2)$$

Where:
m1 = Tray weight (g)
m2 = The weight of the test object after rotating 300 revolutions (g)

Asphalt Drain Down (ADD)

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 ADD value, the ADD test was conducted using the equation below, referring to AASHTO T 305 **Equation 2** as follows [30]:

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

Where:
m1 = tray weight (g)
m2 = the weight of the mold along with the asphalt mixture before being baked (g) m3 = the weight of the mold along with the asphalt mixture after being baked (g)

Indirect Tensile Strenght (ITS)

These tests are performed to give an indication of the mechanical performance of the mixture and evaluate susceptibility to moisture [34]. Due to the porous nature of PA specimens, it is not possible to archive the saturation level required by typical testing procedures with the AASHTO T283 standard [35]. Minimum values for PA mix TSR differ according to road authority requirements, but usually required TSR values are greater than or equal to 90% [33]

III. RESULTS AND DISCUSSION

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

Spesification	**Value**	**AP1**	**AP2****	**AP3**	**AP4**	**AP5**	**AP6***	**AP7**	**AP8**	**AP9**
Stabilitas Marshall	> 500	500,35	699,97	530,41	605,10	560,66	842,70	567,49	500,41	558,097
Void in Mix	15-25 %	17,22	16,48	15,39	16,62	15,16	16,60	14,38	16,95	16,32
Cantabro Loss	< 20%	15,29	8,12	11,01	10,96	12,97	7,50	10,10	15	10,34
Asphalt Drain Down	< 0,3%	0,480	0,140	0,250	0,10	0,240	0,130	0,11	0,39	0,37
Permeability	>0,01	0,093	0,091	0,089	0,090	0,086	0,090	0,081	0,092	0,082
Indirect Tensile Strenght	Min 90%	90,09	94,22%	91,72	95,47	92,92	95,28	93,77	90,12	91,97

Mixed Type Information:

- (AP1) Control 0%
- (AP2) Modified Porous Asphalt with nano CaCO3 2%**
- (AP3) Modified Porous Asphalt with nano CaCO3 3%
- (AP4) Modified Porous Asphalt with BGA 3%
- (AP5) Modified Porous Asphalt with BGA 4%
- (AP6) Modified Porous Asphalt with nano CaCO3 2% + BGA 3%*
- (AP7) Modified Porous Asphalt with nano CaCO3 3% + BGA 3%
- (AP8) Modified Porous Asphalt with nano CaCO3 2% + BGA 4%
- (AP9) Modified Porous Asphalt with nano CaCO3 3% + BGA 4%

Based on the test results and the process of implementing this test, several things were obtained as follows:

1. Based on Marshall Stability scores, all nine types of mixtures made can meet the required specifications. Modified Porous Asphalt with Nano caCO3 and BGA resulted in the highest stability value of 842.70 kg. From **Figure 3.1** it can be seen that with the addition of 3% BGA and 2% nao CaCO3 is able to

increase the stability value. The stability value is influenced by the frictional resistance and interlocking that occurs between the aggregate particles and the cohesion of the mixture. The strength of cohesion increases along with the increase in the amount of asphalt that covers the aggregate, the asphalt content contained in BGA. The nano CaCO3 is able to absorb into the mixture so as to provide good binding power to the mixture and maintain the condition of the mixture from contact pressure between aggregates.

2. Based on VIM values, the five types of mixtures made can meet the required specifications. From **Figure 3.2** it can be concluded that the addition of % BGA with nano material will make the VIM value small. The decrease in VIM value occurs due to the increasing amount of asphalt that fills the voids in the mixture, so that the remaining cavities or air cavities in the mixture are getting smaller. The lower the VIM value, the higher the risk of the mixture bleeding and the higher the risk of the mixture experiencing a decrease in durability. It can be concluded that the mixture that does not meet the VIM value according to the specification of 15% - 25% is the addition of 3% BGA with 3% nano CaCO3 and 4% BGA with 3% nano CaCO3

3. Cantabro Loss testing is carried out to show the resistance of a specimen to friction stress or abrasion, the smaller the weight loss that occurs on the specimen means the more resistant the specimen is to friction or abrasion. The use of 2% nano CaCO3 and 3% BGA in porous asphalt mixtures shows a smaller weight loss than other mixture variations as shown in **Figure 3.3** above. This strongly proves that the ability of nano CaCO3 is very good in terms of binding and also maintaining fish between mixtures. It can also be said that the ability of the two materials is also quite good. With the addition of asphalt content in each material can reduce the abrasion value and bear the bond between aggregates.

4. Open graded porous asphalt mixtures are susceptible to the drain off process, namely the descent of asphalt into the layer below which results in reduced bonds between aggregates and the potential for segregation From **Figure 3.4** above, it can be seen that with the addition of nano material, CaCO3 is able to strengthen the bond of the mixture, this is because the absorption properties of the nano material can minimize the decrease in asphalt in the mixture. For the addition of BGA to the porous asphalt mixture can also be seen to have a good effect which is shown by the required results of < 0.3% in each addition of asphalt content, meaning that the influence of BGA also provides good bonding so that the asphalt reduction is smaller. The ability to bind and envelop aggregates is quite good.

5. This reduction in cavities will certainly be related to the ability of the mixture to drain water. This can be seen in **Figure 3.5** with reduced permeability. With this in mind, it can generally be seen that the addition of additives, especially BGA and nano CaCO3 improves the performance of porous paved mixtures by not significantly reducing their ability to drain water from within the pavement structure.

6. Indirect Tensile Strength is a measure of the ability of a paved 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. As for nano CaCO3 in porous asphalt mixture can also increase the modoulus stiffness value, it can be seen by the second highest ratio level, the addition of 2% CaCO3 into the porous asphalt mixture with BGA 3% can improve the characteristics of the mixture, nano CaCO3 contributes to increased cohesion properties so that the mixture can maintain aggregate.

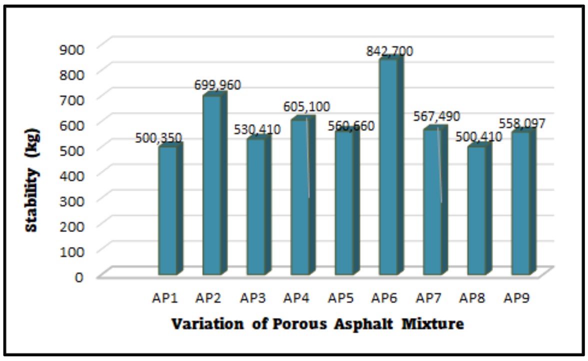


Figure 3.1 Marshall Stability Graph

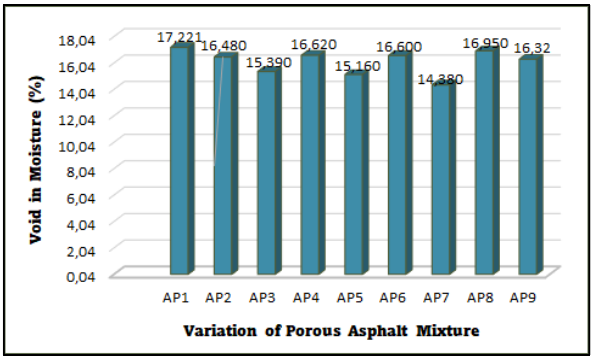


Figure 3.2 Void in Mix Graph

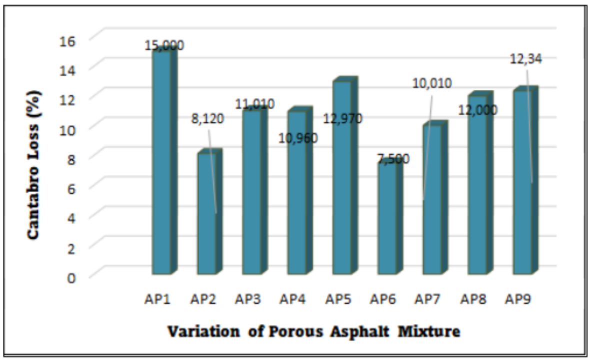


Figure 3.3 Cantabro Loss Graph

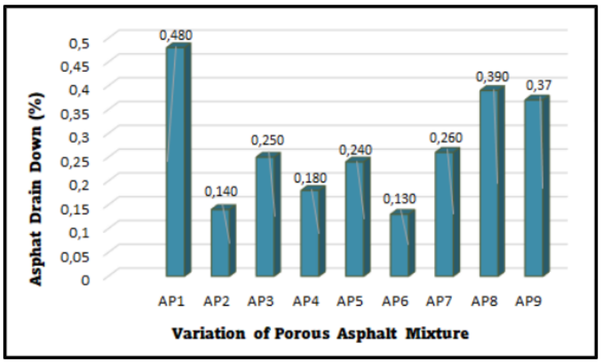


Figure 3.4 Asphalt Drain Down Graph

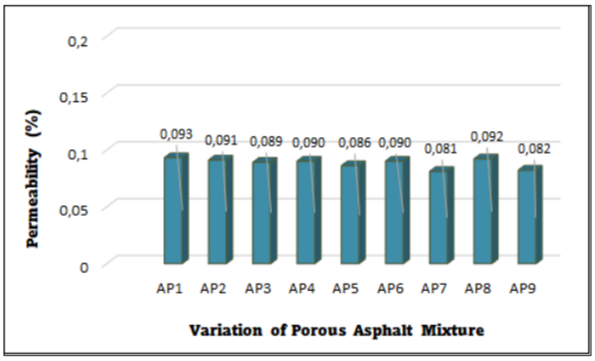


Figure 3.5 Permeability Graph

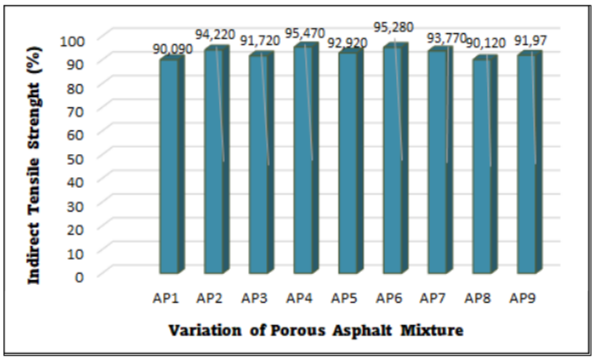


Figure 3.6 Indirect Tensile Strenght Graph

IV. CONCLUSIONS

The results obtained in this study show that the addition of nano CacO3 with the right percentage and also BGA can be promising as an added material for which can improve the performance of porous asphalt mixture from several parameters, namely Stability, Void in Moisture, Cantabro Loss, asphalt Drain Down and Indirect Tensile Strength. Of the nine variations, it can be seen that the addition of 2% nano CaCO3 and 3% BGA is the best percentage, although the addition decreases the permeability of the mixture. It is likely that this is affected by additional material covering the cavity, but overal this value does not significantly reduce its ability to drain water from within the pavement structure. The addition of CaCO3 nano material is able to strengthen the bond of the mixture, this is because the absorption properties of the nano material can minimize the decrease in asphalt in the mixture. Likewise, the influence of BGA also provides good bonding so that the asphalt drop is smaller. So that it can increase strength

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