JURNAL REKAYASA SIPIL (JRS-UNAND)
Vol. 15 No. 2, November 2019
Diterbitkan oleh:
Jurusan Teknik Sipil, Fakultas Teknik, Universitas Andalas (Unand)
ISSN (Print) : 1858-2133
ISSN (Online) : 2477-3484
http://jrs.ft.unand.ac.id

IMPROVING STRENGTH OF POROUS ASPHALT: UTILIZING FLY ASH INTO NANOMATERIALS IN EXPERIMENTAL APPROACH

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Manuscript received: 16 September 2019. Accepted: 10 November 2019

ABSTRACT

Porous asphalt (PA) has potential to be utilized in many urban area in Indonesia which often faced high street runoff during rainy season. PA can be a solution for storm water management. A typical porous pavement has an open-graded surface over an underlying stone recharge bed. The water drains through the porous asphalt and into the stone bed, then, slowly, infiltrates into the soil. However, despite of the benefit of porous asphalt, there is still weaknesses, such as less of service life than dense-graded asphalt due to its lower durability and strength. In order to improve durability and strength of PA, this study investigates the effect of utilizing fly ash (FA) class F in porous asphalt (PA) mixture as replacement in aggregate gradation and perform as filler. Mechanical activation (grinding) of fly ash was performed resulting in reduction of particle size. This material gives more strength since the more of surface area that can bind in finer particle size. Utilizing fly ash into nanomaterial is one of the methods for this study. Material approaches for nanomaterial were proposed by breaking up larger particles with physical processes such as grinding or milling. This is called mechanical activation. Since asphalt pen 60/70 is mainly binder material in Indonesia, it is used as the default for all samples in this experiment. The optimum bitumen content (OBC) was determined for all the mix by Marshall mix design. In view of the nanomaterial approach, samples were then prepared for the same optimum bitumen content (5.85%) by using Bina-Marga's PA standard in control mix as well as natural FA and modified FA as alternative filler in modified mixes. modified FA itself has been milled using transversal ball mill machine for 3 to 6 hours. This experimental study indicated higher stability value and reduction of permeability with the same OBC for the mixture having modified FA as filler content in comparison with standard mix and natural FA mix. All sample conformed with Indonesian asphalt porous Specification. This trends will become as a starting point for improvement in the future research. For further research, binder modification with added material such as rubber or nanoparticles are highly recommended to improve strength and durability of asphalt porous. However, another method need to be proposed for reduction of particle size in fly ash into nanomaterial range.

Keywords: porous asphalt, nanomaterial, fly ash, alternative filler

DOI : https://doi.org/10.25077/jrs.15.2.75-89.2019

1. INTRODUCTION

Nanomaterials are one of many nanoscience and nanotechnology applied details. It is potential to revolutionizing how the materials product and the function are increasing. Nanomaterials are categorized as a set of substances where at least one dimension is less than 1000 nanometers. A nanometer is one millionth of a millimeter (Alagarasi, 2011).

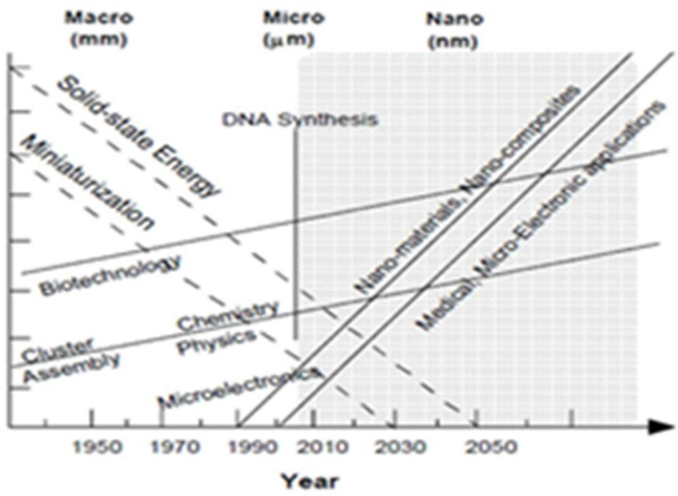

Fig 1. Evolution and Timeline of Nanoscience and Technology

In this case, fly-ash will be utilized as a nanomaterials filler for porous asphalt. Nanomaterials basically on their nature, using a specific dimension. At the end, they expose some specific characteristics, qualities, even features compared to commonly materials that used (S. K. Karatzas, 2018).

Porous asphalt has so many advantages in application for infrastructure. At the beginning steps, with proper design and installation, porous asphalt pavements can provide a cost-effective solution for storm water management in an environmentally friendly way (NAPA, 2019). Although it has limitations in terms of durability and strength, this research discussed the optimization of asphalt porous can be determined. For this research, fly ash was used as alternative filler for void reduction but still maintaining for drains. To satisfy fly ash as filler, modification in terms of size was conducted.

Bituminous materials, such as asphalt, are used on a large scale road construction projects in Indonesia. There are three mainly types of pavement that has been used in Indonesia such as; dense-graded mixtures, open-graded mixtures (Porous Asphalt), and rigid pavement. Dense-grade mixtures and rigid pavement are the mainly used on road construction in Indonesia. However, number of flood on the surface of the pavement are extremely high during in wet season. Since dense-graded mixtures and rigid pavement has a characteristic that only drain the water to nearest drainage system through surfaces, it means that this type of pavement depend to another infrastructures such as drainage system. However, porous asphalt has something different than the other type of pavement. First used in 1950's in the United States, and become popular in the 1980's by more than 200 projects of porous asphalt designed by Cahill Associate, this type of pavement allow water to drain infiltrate through surfaces. This might be suitable in Indonesian road since the porous asphalt construction will gives more space for water to drain before reach the nearest drainage system (Cahill, Adams, & Marm, 2005).

Despite of the benefit of porous asphalt, there is still weaknesses in porous asphalt such as less of service life than open-graded or rigid pavement, and its durability and strength. There are two type of modification to improve it such as binder modification or aggregates modification. Since asphalt Pen 60/70 is the mainly used binder material in Indonesia, so Pen 60/70 become the default of all samples in this research. It will be easier to construct when all the material are the mainly used and available all across the country. Because of Pen 60/70 become the default, the modification will be in aggregate (Kar, Panda, & Giri, 2014). As a hydrophobic (non-water wettable) characteristic, fly-ash are potentially reduce the striping-off asphalt. Fly ash occupy gradation, organic impurities, and plasticity for mineral filler specification (FHWA, 2017).

For this research, utilization fly ash has been proposed. As we all know, fly ash has been proposed for the application of high performance concrete as supplementary cementitious materials (SCM). The utilization of fly ash as cement replacement has been well documented. Many researchers were investigating the effect of fly ash as supplementary cementitious materials (SCM) (Sobolev, 2003). Up to date, researches have been conducted using fly ash as pozzolanic material focusing on strength development and densified structure based composites. Ultra-fine particles can provide a nucleation effect initiating and accelerating hydration (Celik, Damcı, & Pişkin, 2008). It is reported that the finer particles of fly ash can be used to achieve higher compressive strength (Collepardi, Collepardi, Skarp, & Troli, 2004).

For this reason, utilization of fly ash was proposed by milling process (mechanical activation) resulting in finer particles. The mechanical activation can be realized using a conventional milling process. Due to activation and dispersion process, fly ash products with high fineness can be achieved. Additionally, milling of fly ash into smaller particles act as filler thus result in a higher strength and durability. The activated fly ash with higher fineness results in the nano material range (1- 200 nm). Therefore, replacement of fly ash as aggregate modification was mixed into porous asphalt and hopefully it will improve its durability and act as filler for reducing the striping-off asphalt

2. RESEARCH OBJECTIVES AND METHODOLOGY

The study aimed to analyze the effect of utilizing fly ash (FA) class F in porous asphalt (PA) mixture as replacement in aggregate gradation and perform as filler. To improve strength and durability of porous asphalt this research will identify how fly ash will react when it combined in the porous asphalt mixtures. Since fly ash filling the pores between porous asphalt mixtures as a filler, this process will reduce the permeability and improve the strength of asphalt porous. However, amount of fly ash should be analyzed to get the optimum composition.

The experiment divided into several step to analyze the correct amount of FA in mixture for porous asphalt. Based on Indonesia standard for porous asphalt, first of all, the optimum asphalt content need to be specified first from the provided samples. Therefore, from the optimum asphalt content, the use of fly ash as replacement was added into the mixture. Then, mechanical activation was performed. Fly ash was milled for certain duration to obtain the optimum results for approaching nanomaterial. This modified fly ash was added into porous asphalt mixture and tested for Marshall test, Cantabro test and permeability test.

There are three kind of sample which will be use the gradation content specification of porous asphalt that has been standardized by Bina Marga (Ministry of Public Works in Indonesia) in 2012. The three kind of samples are; with optimum bitumen content, 18% of fly ash (class F), and 3,6% of fly ash that has been milled using transversal ball mill machine for 3 to 6 hours. Using original fly ash and milled fly ash class F as a replacement in aggregate content will reduce its permeability and improve its durability. To investigate of sample characteristics, several test such as Cantabro loss, Marshall test and permeability test will be tested in transportation laboratories. Another test will be held in physics laboratories by using transversal ball mill machine and nano material laboratories by using scanning electron microscope (SEM) and X-ray diffraction (XRD) facility (PUPR, 2012).

3. MATERIALS AND EXPERIMENTAL PROCEDURES

3.1. Asphalt Porous Mix Design

Mix design of porous asphalt has various standards depend on the availability of resources and the climate of a country that observed. In Indonesia, ministry of public works has established a standard in 2012 about guidance for porous asphalt. This research will use the specification of Indonesian standard with the gradation of aggregate shown below in **Table 1**.

Table 1. Indonesian Porous Asphalt Gradation of Aggregate

Sieve Number		Spec	Percent Pass Avg	Percent Retained
(ASTM)	(mm)			
1”	25,000	100	100	0
3/4”	19,000	95 – 100	97,5	2,5
1/2"	12,500	64 – 84	74	23,5
4	4,750	10 – 31	20,5	53,5
8	2,360	10 – 20	15	5,5
200	0,075	3 – 7	5	10
Pan				5

To find the optimum asphalt content, there are 15 sample with various asphalt content from 4%, 5%, 6%, 7%, and 8%. Each sample will has weight about 1100 grams. After measuring the gradation, aggregates will be heat up until reach 164 °C, and will be mixed with asphalt in temperature of 154 °C.

Several test will conduct based on the Indonesian specification of porous asphalt. There are three kinds of test that will be a criteria to find the optimum asphalt content. The three kinds test are:

1. Asphalt Drain-down test
2. Cantabro Loss test
3. Marshall Stability test

Asphalt drain-down test is a test to quantify amount of asphalt that has been dripped from the porous asphalt mixtures. For open gradation mixtures or asphalt porous this test is a special test. The sample of asphalt mixtures will be put in into a bucket without compacted before. After that, the bucket will be put in into an oven for 65 minutes.

$$\text{Asphalt Drain-down} = \frac{A-B}{C}\ x\ 100$$

Where:
A = Final weight of plate (gr)
B = Initial weight of plate (gr)
C = Initial total sample weight, g

Cantabro loss test is a test to quantify the abrasion loss of pavement mixtures. There are two type of this test which are with steel ball and without steel ball. First aggregate mixture was compacted with hammer for 50 times of blows each size. The sample will be put in into abrasion Los Angeles Machine with 300 revolutions.

$$CL \quad = \frac{A-B}{A}\ x\ 100$$

Where:
CL = Cantabro Loss,
% A = Initial weight of test sample
B = Final weight of test sample

The last test for finding optimum asphalt content is marshall stability test. This test will quantify the factor of mixtures marshall factor. This test will show how much pores that created inside the sample with the same sample procedure with cantabro loss. The output of this test are such as:

1. Flow
2. Marshall Quotient
3. Void in Mixtures (VIM)
4. Voids in the Mineral Aggregate (VMA)
5. Voids Filled with Bitumen (VFB)

Stability of marshall is the maximum load that the sample can bear before it crushed with a constant load at 55mm/minute.

As the result of asphalt drain-down, cantabro, and marshall stability test, it shown at the **Table 2.**

Table 2. Result of Average Sample

Mixtures Characteristics	**Asphalt Content (%)**					**Spec**
	4	5	6	7	8	
Asphalt Draindown	0,00	0,00	0,00	0,01	0,03	< 0,3
VIM	22,1	21,1	19,4	17,04	15,8	17 - 23
Cantbro Loss	23,3	14,8	11,9	6,64	6,88	< 20
Marshall Stability	506,7	402,7	383,7	531,1	351,5	>350

The amount of optimum asphalt content have to fulfill the specification that has been stated. For Indonesian specification have to fulfill criteria such as VIM, marshal stability, asphalt draindown and cantabro loss. Figure 2 until 5 will show the result of each test. From the test, the optimum asphalt content will be in 5,85% of total weight of the sample.

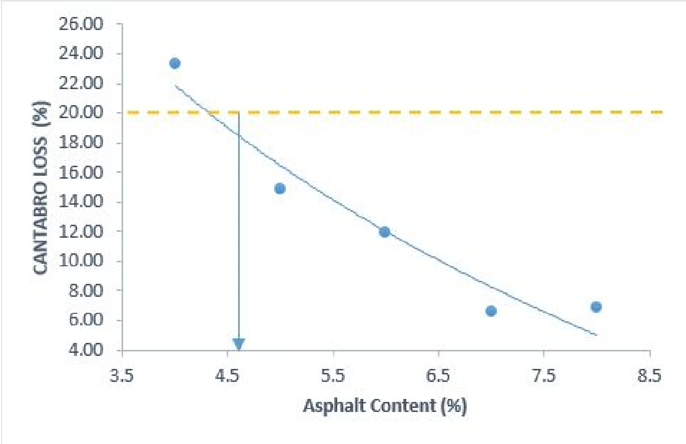

Fig 2 Cantabro Loss Graphic

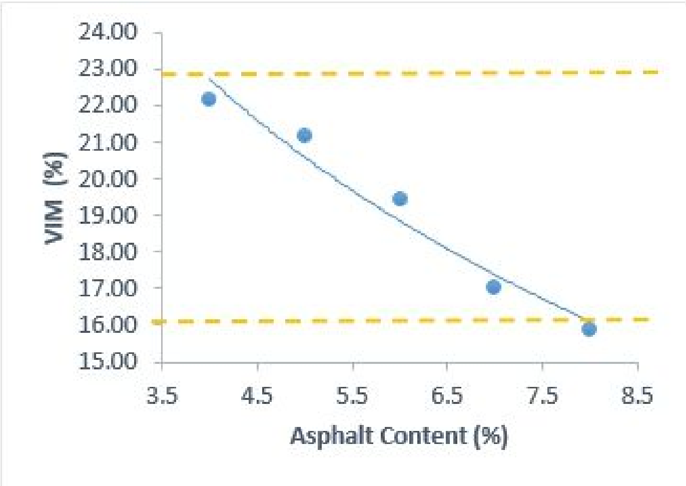

Fig 3 VIM Graphic

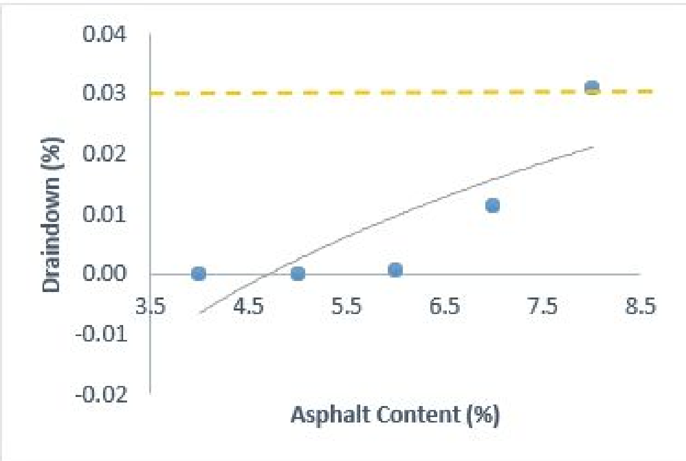

Fig 4 Draindown Loss Graphic

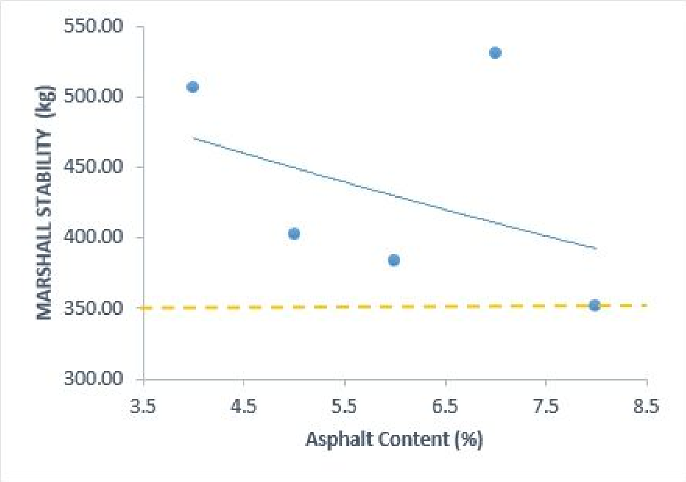

Fig 5 Marshall Stability Graphic

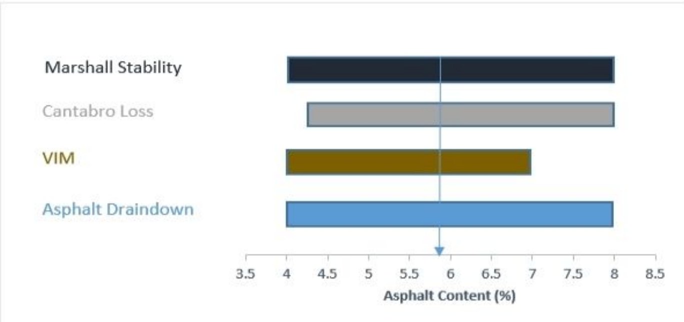

Fig 6 Result of Cantabro Loss, VIM, Asphalt Draindown, Marshall Stability

3.2. Fly Ash Replacement

The use of fly ash in Indonesia has been implemented in many construction site. This material can reduce the heat of hydration because of cementious material that can generates heat. In asphalt mixtures, fly ash will become a filler that can fill into a small pores inside it. This material is very cheap and available across the country, because fly ash is a waste material from coal mining. However, to find the optimum composition, there are several test to conduct such as:

1. Ball Milling Process
2. Scanning Electron Microscope test
3. X-Ray Diffraction test

Since this research was conducted the modification of aggregate not the binder content, the replacement aggregate with fly ash would be investigated. Fly ash class F will be treated first before it pour to the asphalt porous mixtures. Mechanical activation was performed by dry transversal ball-milling for several hours. The original fly ash was placed into the tube and then shacked together with balls of grinding media. This process will take for 3-6 hours until the size of fly ash turns into smaller particles. There are 30 small balls which has 0,5 grams of weight and 3 big balls which has 1 grams of weight. Refer to **Fig 7 and 8,** the dimension and common shape of Transversal Ball Mill shown below. The new aggregate is called the modified fly ash.

Fig 7 Transversal Ball Mill

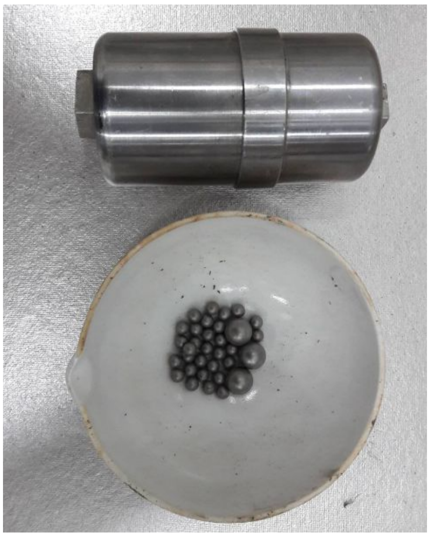

Fig 8 Tube and Balls for Fly Ash Milling Process

After 3-6 hours the particle size of fly ash has been reduced. This indicates by milling process, fly ash can be shifted smaller size and close to nanomaterial range. Before the milling process or the original size of the particle size is up to 3000 nm (3 μm). By using finer particle size, it will improve the durability of the porous asphalt because this finer particles will fill the pores between aggregates. To know the particle size has been reduced, further analysis is investigated by scanning electron microscope (SEM). The result of the SEM will be shown on **Fig. 9** below.

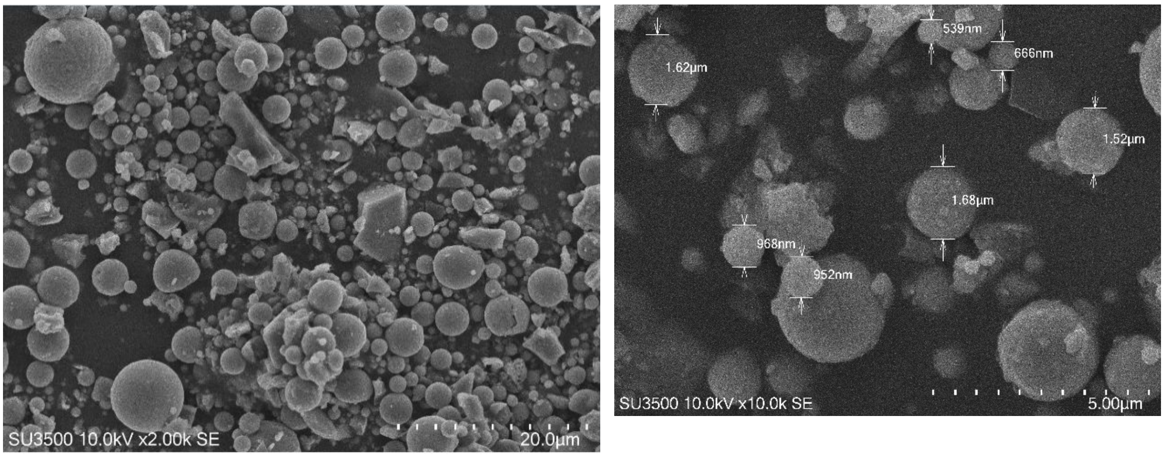

Fig 9 3-6 Hours After Milling Process

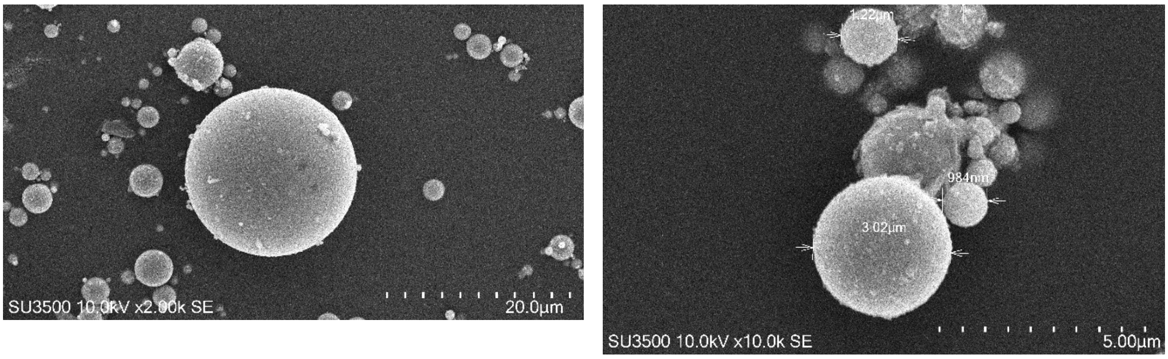

Fig 10 Original Size of Fly Ash F

From the result of SEM, it was shown that the original fly ash has a round shape and bigger size than 3-6 hours fly ash that has been milled and resulted in smaller size without heat transfer. The modified fly ash has a cracked form because there is a crushed process between balls, tube and the fly ash. These finer particles could probably filling up the void into porous asphalt due to improved bond between mixtures which is generated by smaller particles close to nanomaterial. This allows crystallite reduction to finer particles, resulting in higher reactivity than original fly ash.

It's better under 6 hours of milling process, because the more hours of milling process that fly ash gets will gives a hydration responses. This responses comes from the heat that generates between tube and balls. Fly ash should not react yet into another forms of structure before it pour into an asphalt mixtures. In some cases, fly ash react each other and become a new shape because of heat that generates after 24 hours of milling process. Our goal was heat released from fly ash when combined with asphalt mixtures and finally become binder resulting in higher strength.

Another test to find the characteristics of nano particle is X-Ray Diffraction. X-Ray diffraction is used for a wide variety of material characterization studies. Primarily, the technique identifies crystalline phases in a material. The result from an XRD analysis is a diffractogram showing the intensity as a function of the diffraction angles. The upper graphic is a graphic for modified fly ash and the other one is a graphic. Quartz peaks from fly ash is at 26, like shown in **Fig.11** below.

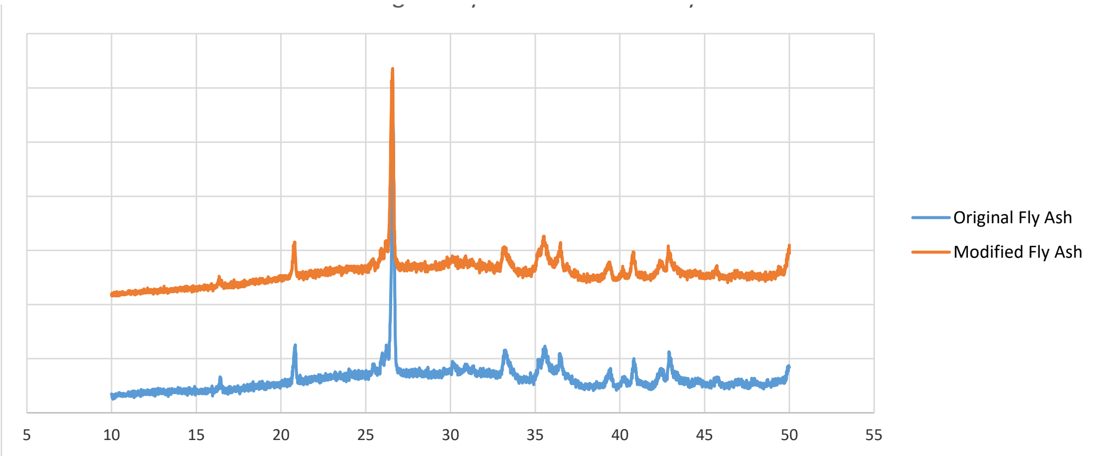

Fig 11 XRD diffractogram

3.3. Permeability Test

After findings the characteristics of fly ash in physics laboratories, another test will conduct later. There are three main criteria to compare all of the sample which are Marshall stability, Cantabro Loss and permeability test. For permeability test, this research will conducting falling head permeability method. There are two method for permeability test, first constant head and the second one is falling head method. Constant head method is suitable for sample which has high permeability ability ($k > 10^{-3}$ cm/s) This method is suitable for this sample because this material has a low permeable ability which has the value of k is about 10^{-3} cm/s to 10^{-5} cm/s.

$$k = \frac{a.L}{A.\Delta t}.\ln(\frac{h1}{h2})$$

Where:

k	= Permeability coefficient
L	= height of sample
h1	= initial height of water
h2	= final height of water
A	= area of sample
Δt	= time that needs from h1 to h2

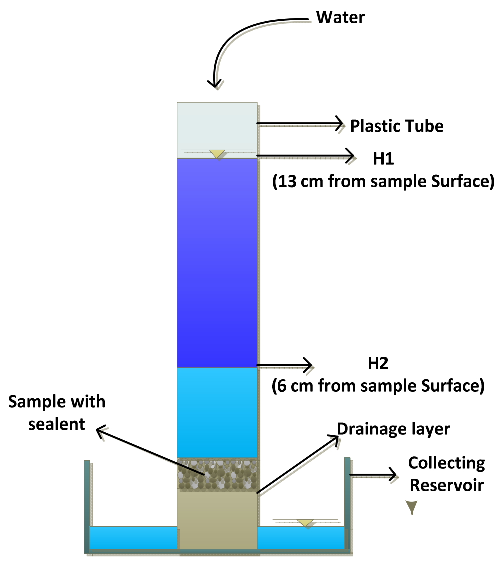

Fig 12 Permeability Test

Refer to **Fig. 12** simulation, The height of h1 is 13 cm above the sample surface, and h2 is 6 cm above the sample surface. First of all, water have to pour into the plastic tube until it has height higher than h1. Stopwatch starts when water starts to drain through the sample reach h1 point and finish when water reach h2 point, this is call Δt. It is very recommended to seal the sample tightly. On our first trial, water runs through the gap between seal and sample. So, it's very important to make sure that water runs through the sample for a precision result.

4. RESULT

After several test, there are three samples that has been tested. The three types of sample are:

1. With Optimum Bitumen Content (OBC)
2. With OBC + Natural Fly Ash F (OBC + FAF)
3. OBC + Fly Ash Modified (OBC + FAFM)

All the samples will be tested based on Indonesian asphalt porous Specification. Samples with optimum asphalt content has a proportion of asphalt content is 5,85%. The second samples is OBC with a replacement of fly ash in aggregate contens. With 18% of replacement of fly ash (200 gram), the gradation will be modified **Table 4**. The last type of sample is OBC + Fly Ash Modified. This fly ash has been milled in transversal balling machine for 3-6 hours and has been tested in SEM and XRD to make sure the particle size already finer than the original fly ash. The reduction of particle size will gives more durability to the sample since it can fill pores between aggregates. The proportion of aggregate content will be shown at **Table 5**.

Table 3. OBC's Aggregates Content

Sieve Number		Percent Pass	Percent Retained	Gram
(ASTM)	(mm)	Avg		
1"	25	100	0	0
3/4"	19	97,5	2,5	27,5
1/2"	12,5	74	23,5	258,5
4	4,75	20,5	53,5	588,5
8	2,36	15	5,5	60,5
200	0,075	5	10	110
Pan			5	55

Table 4 OBC + Natural Fly Ash F Aggregates Content

Sieve Number		Percent Pass	Percent Retained	Gram
(ASTM)	(mm)	Avg		
1"	25	100	0	0
3/4"	19	97,5	2,5	27,5
1/2"	12,5	74	14,41	158,5
4	4,75	20,5	44,41	488,5
8	2,36	15	5,5	60,5
200	0,075	5	10	110
Pan			5	55
Fly Ash Original			18,18	200
Total Weight				1100

Table 5 OBC + Modified Fly Ash Aggregates Content

Sieve Number		Percent Pass	Percent Retained	Gram
(ASTM)	(mm)	Avg		
1"	25	100	0	0
3/4"	19	97,5	2,5	27,5
1/2"	12,5	74	23,50	258,5
4	4,75	20,5	50,59	556,5
8	2,36	15	5,5	60,5
200	0,075	5	10	110
Pan			5	55
Fly Ash Original			2,91	32
Total Weight				1100

All sample has the same procedure such as, mixing temperature and number of blown (50 blown hammered each side). After all the samples already mixed, all the samples has to be tested in cantabro loss, marshall test and permeability test. As mention above, the more use of fly ash replacement in aggregate content will improve its durability but reduce permeability. Tabel. 6 will show the impact of fly ash replacement in aggregate content.

Table 6 OBC's Aggregates Content

Testing Measure	Unit	Spec	Type		
			OBC	OBC + FAF	OBC + FAFM
Marshall Stability	kg	>350	**497**	**1079**	**779**
Cantabro Loss	%	< 20	**10.47**	**19.14**	**7.89**
VIM	%	17 - 23	**18.12**	**9,67**	**17.06**
Permeability Test	cm/s	0.001	**0.44942**	**0.00045**	**0.186**

The result shows that with OBC in 5,85 %, the sample only can bear 497 kg. However the result in OBC + FAF because can bear up to 1079 kg. In the middle range is OBC + FAFM with 779 kg. All the samples passed the requirement of the specification. The percentage of VIM of all the sample are in linear line. Since the more finer particles was pour into the mixtures, the less permeable it gets. In VIM, OBC + FAF's sample doesn't has a requirement because it has lesser percentage than the specification with only 9,67%

In cantabro loss, all the samples passed the requirement. The percentage of cantabro loss in OBC sample has 10,47% loss, and in OBC + FAF sample has 19.14% loss. However, the percentage has been reduce in OBC + FAFM sample. The reason why OBC + FAF has more percent loss than the other is because its gradation has more finer material than the other. This finer material fill in pores between aggregates so it can gives more strength in marshall stability test, but in cantabro loss test the finer aggregate can't bear the impact of its revolutions especially for finer material that has located on the side of the sample. In OBC + FAFM the percent of loss is only 7,89%, it's because of, amount of finer material has lesser and only 32 gram or 2,91% from the total weight. This modified fly ash has more finer particles and it has particle size up to 200nm. This particles can fill inside the pores in nano meter, not only in mikrometer like natural fly ash. This material gives more strenght since the more of surface area that can bind in nano meter scale.

In permeability test, OBC has the most absorbence than the other sample. it has coefficient of permeability 0,44cm/s. Only OBC + FAF that has not requirement into an asphalt porous specification because it has less value of permeability coefficient which is only 0,00045 and it's below the specification. OBC + FAFM sample was passed the requirement of asphalt porous specification even has lesser value of permeability coefficien than OBC's sample.

Afterall Nanomaterials are bringing the new solutions to current dynamics industrial challenge. Porous Asphalt pavements hopes increasing the feature and function of the road itself. Transforming the pavement become to the "Smart Road", porous asphalt could handling more run-off water surface of rainfall. The idea was Avoiding the aquaplanning in the pavement with collecting water run-off to drainage by utilizing the hydrophobic nanomaterials as porous filler. This condition was so close, relate to Indonesia as a tropical country with a high debit of water rainfall during wet season. Alongside with the potential of nanomaterials, there are appear some issues to concern about. Main issues looking for human health anf environment that might going on with the development. The other issues are about the scale. Combination of bulk aggregates and binders should be evaluate to reasure that the benefits of nanomaterials technology are still applicable and have more added value with these scale.(S. Karatzas, 2018). In more spesific details, modified fly ash caterogized in an acceptable durability. Otherwise modified fly ash have more permeability index than the original fly ash. This is going to be the next topics to generate how creating the modified fly ash with high durability and strength permeability.

5. CONCLUSION

From the result, the more finer material pour into the asphalt mixture will gives more strength but it has to be less than 200 grams. In 200 grams of fly ash material replacement, when it comes to permeability test, the water still can drain through asphalt mixture it means that the sample still has a permeable characteristics, not impermeable. It indicates improvement in terms of durability. These finer particles could probably filling up the void into porous asphalt due to improved bond between mixtures which is generated by smaller particles close to nanomaterial. This allows crystallite reduction to finer particles, resulting in higher reactivity than original fly ash. However, another method need to be proposed for reduction of particle size in fly ash resulting in uniformly sizes into nanomaterial range.

The reduction of finer material from micro meter scale to approximately nano scale is proved to improve more strength in porous asphalt mixtures. This material gives more strength since the more of surface area that can bind in finer particle size..

Performance evaluation of porous asphalt using modified fly ash demonstrated some improvement in terms of durability and strength. However, methodology for modified fly ash need to be reassure despite of limited samples. From the experimental results, the modified fly ash indicates that mechanical activation (grinding) in ball mill can improve the strength of porous asphalt binder. Indeed, it can be concluded that such improvement is due to the use of ultrafine particles of fly ash. Here, the product with higher surface area (finer particles) provided a better performance with regards the introduction of the nucleation sites for the formation C-S-H resulting in densified structure.

The study could be further improved by incorporating from references of previous study and additional mixtures between fly ash itself and with other nanoparticles such as nano-silica combined in porous asphalt mixtures. Such optimization is essential when the combination of asphalt bitumen, fly ash and nanoparticles is used.

6. RECOMMENDATION

Pen 60/70 is the mainly used for asphalt mixtures in dense-graded gradation but not good enough for porous asphalt gradation. For further research, the modification of binder are recommended to improve strength and durability of asphalt porous. The binder modification with added material such as rubber or nanoparticles are highly recommend.

AKNOWLEDGMENTS

The authors wish to extend their gratitude and appreciation to the Institute of Research and Community Outreach of ITB who provided the grant for this research under the P3MI Program.

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