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Moisture susceptibility of porous asphalt mixture with Nano silica modified asphalt binder

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Abstract. This paper presents the mechanical properties of porous asphalt (PA) with nanosilica (NS) modified asphalt binder in terms of its Moisture Susceptibility. This test is essential to evaluate the performance of NS-PA towards the resistance of moisture induced damage. Moisture susceptibility can be defined as the loss durability, strength and stiffness of PA due to the existence of moisture, causing the adhesive loss of binder and aggregate. It is interesting to know that the existence of nanoparticle with different proportion can affect the moisture susceptibility behavior of NS-PA. Three different percentages of nanosilica were mixed with PEN 60-70 type of binder in this study. Then, all these blended modified binder were used to prepare PA Grading B specimens using Marshall Mix Design Method. Nanoparticle used in this study was Nanosilica with the average size of 10 to 15 nanometer. In addition, Moisture Susceptibility of NS-PA was evaluated using Indirect Tensile Strength Test, based on Modified Lottman Test. From the result, the maximum TSR value obtained at 2% NS-PA, which was 91%. Meanwhile, for conventional PA (0% NS), TSR value was only 74%. In accordance to AASTHOT283, TSR value should be equal or more than 80% to withstand moisture induced damage. However, for PA, 70% TSR value is consider acceptable due to porous nature of PA that permit water to flow inside the mix. From this result, it was concluded that the optimum amount of NS required for PA to withstand moisture induced damage was 2%. Thus, with proper NS concentration, the performance of PA with NS modified binder in terms of moisture susceptibility can be enhanced.

1. Introduction

PA is generally considered as a non-structural layer of flexible pavement. However, it should possess sufficient strength in bearing the external loads imposed by vehicular traffic [1]. Some mechanical properties owned by conventional asphalt layer such as dynamic modulus, rutting resistance, stripping potential, resilient modulus, indirect tensile strength, and stability should also be evaluated for PA. This is important since PA forms the uppermost layer of flexible pavement, thus receiving the loads from moving traffic directly. The mechanical properties of PA greatly depend on several factors and one of them is related to the binder used. According to Public Work Department of Malaysia [2], PA generally has a total percentage of voids between the range of 20 % to 25 % which is relatively high compared to that conventional hot mixed asphalt. The high voids content in PA have been enabled through the use open-graded type of aggregates. Open gradation mainly consists of coarse aggregates with size dimension larger than 2.36 mm (No. 10 sieve) together with small amount of fine aggregates (not more than 15 %) and also mineral filler not exceeding 5 % of the total aggregate weight [3]. Hence, this type of gradation produces relatively high interconnected air voids after compaction.

PA is a type of mixture that solve the issue that related to storm water drainage from parking and other low traffic density areas. [4] Porous asphalt also namely open-graded asphalt has been used as a wearing surface since the 1950s. Its first major use in Australia was about 1973 and in Japan was about 1987. Porous asphalt is a developing in road surfacing technology. Porous asphalt is an innovative road surfacing technology, which allows water to enter into the asphalt mixes beyond its continuous air voids [5]. Porous asphalt designed so that after laying and compacting, they form a surface with voids more than 20 percent. They are used in wearing courses and always laid on impervious base course, was promising and effective in enhancing traffic safety [6]. Due to its drainage capability, PA suffers some drawbacks such as stripping. This will cause adhesion and cohesion of PA due to the existence of water. This phenomena is called moisture induced damage [7].
In order to monitor this situation using laboratory testing, A Modified Lottman Test is produced to evaluate the moisture induced damage of PA. Indirect Tensile Strength (ITS) Test is used to identify the moisture susceptibility of PA [8]. ITS is a measurement on the elasticity behavior of asphalt. It gives indication on how well will asphalt mixture able to resist the formation of failure like cracks [9]. In accordance to AASHTOT283, the minimum requirement of Tensile Strength Ratio for asphalt mix is 80%. However for PA, 70% TSR is still acceptable. Thus, this study was intended to evaluate the performance of PA in terms of moisture induce resistance with the existence of nanoparticle. This study is also provides an initial indicator whether nanomaterial is reliable in improving the overall properties of PA.

2. Materials

2.1. Asphalt Binder
This study utilized penetration grade 60-70 type of asphalt binder. This virgin asphalt binder was mixed with various amount of NS, from 0% NS (control specimen) up until 6% NS by weight of asphalt binder, with the increment of 2%.

2.2. Aggregates
In this study, crushed granites were used as the aggregates source to include in the specimen's mixtures. The aggregates were obtained from Blacktop Quarry, Rawang Selangor. The aggregates were graded in the range of 14 mm to 0.075 mm size. Porous asphalt grading B was used, where the nominal maximum aggregate size for this type of PA is 14mm. The weight of aggregate for every specimen was about 1100g. Table 1 shows the PA Grading B blended aggregate gradation in accordance to Public Work Department of Malaysia Standard Specification for road works [2].

2.3. Nanosilica
Nanomaterial used in this study was nanosilica. Nanosilica used was in the form of colloidal particle with the average size ranging from 10 to 15 nanometer (nm). Table 2 shows the properties of NS used in this study.

Table 1. PA Grading B.

Size (mm)	Passing (%)	Retained (%)	Retained (g)
20	100	0	0
14	85-100	7.5	82.5
10	55-75	27.5	302.5
5	10-25	47.5	522.5
2.36	5-10	10	110
0.075	2-4	4.5	49.5
Filler		3	33

Table 2. Specification of Nanosilica.

Properties	Value
Appearance	Slight Milky Transparent
SiO_2 (%)	30%
Na_2O (%)	0.5%
pH	8.5-10.5
Density	1.19-1.22 g/cm3
Particle Size	10-15 nm

3. Methodology

3.1. Asphalt Mixing Process

A custom made mechanical binder mixer was used for this process. This equipment consists of steel stirrer (blade), a heater, a stand and a binder bowl. Virgin asphalt binder involves are penetration grade 60-70 type of binder, with 0% amount of NS assigned as control specimen. During the mixing process, continuous stirring took place for an hour with the average heating temperature of 160℃. This stirring process was performed at 1800 revolution per minute. The amount of NS used were 0% t0 6% by weight of asphalt binder with the increment of 2%.

3.2. Indirect Tensile Strength Test

Indirect tensile strength test also known as moisture susceptibility is the most common distress in asphalt pavement. The moisture induced damage was evaluated by moisture susceptibility test procedures (Modified Lottman Test – AASHTO T283). The indirect tensile strength test was performed to determine the tensile properties of cylindrical samples by applied a compression load along a diametrical plane of two opposite loading heads. For indirect tensile strength test, the samples were placed between the steel loading strips using Indirect Tensile Strength Machine. Every NS concentration including the control PA (0%NS) were tested using indirect tensile strength (ITS) Test based on AASTHO T283 [10]. Indirect Tensile Strength (ITS) Test was performed for two conditions of the samples, which were dry and wet condition. For each condition, 12 compacted PA samples totalling 24 samples for two conditions (wet and dry) and 0% NS-PA, 2% NS-PA, 4% NS-PA and 6% NS-PA were tested. For dry sample, the sample was brought to the test temperature of 25˚C by placing the briquettes in a dry temperature control system at 25˚C for 2 hours. The sample was removed from the air cabinet and then placed into loading equipment. The briquette was centered on the edge of the lower loading strip. The upper loading strip was positioned. Next, the assembly was positioned centrally under the loading ram of compression testing device. The load was applied at the rate of 50.8 mm per minute until it reached maximum load. The maximum load was then recorded as P value.

For wet samples, those samples were wrapped with 700 ml of water into wrapper and tied up. The wrapped samples were placed into the water bath at 60˚C temperature for 24 hours. Then, the samples were brought into the basin that contains water at the room temperature for 2 hours. The samples were removed from the basin to be tested. The briquette was centered on the edge of the lower loading strip. The upper loading strip was positioned. Next, the assembly was positioned centrally under the loading ram of compression testing device. The load was applied at the rate of 50.8 mm per minute until it reached maximum load. The maximum load was then recorded also as P value. ITS and Tensile Strength Ratio (TSR) values for each samples were calculated to represent the moisture induced damage of PA. The ratio of the average tensile strength of the dry conditioned and wet conditioned specimens or also known as Tensile Strength Ratio (TSR) was calculated. In accordance to AASTHO T283, the minimum amount of TSR for asphalt mix is 80%. If the value of TSR is ≥80%, the asphalt mix is considering resist to moisture susceptibility, ≤80% indicates that the asphalt mix is sensitive to moisture susceptibility. But, due to porous nature of PA, TSR value ≥70% is consider acceptable. Figure 1 below illustrates the Modified Lottman Test. The maximum compressive load for every samples were recorded and the tensile strength of PA specimens were calculated using Equation 1.

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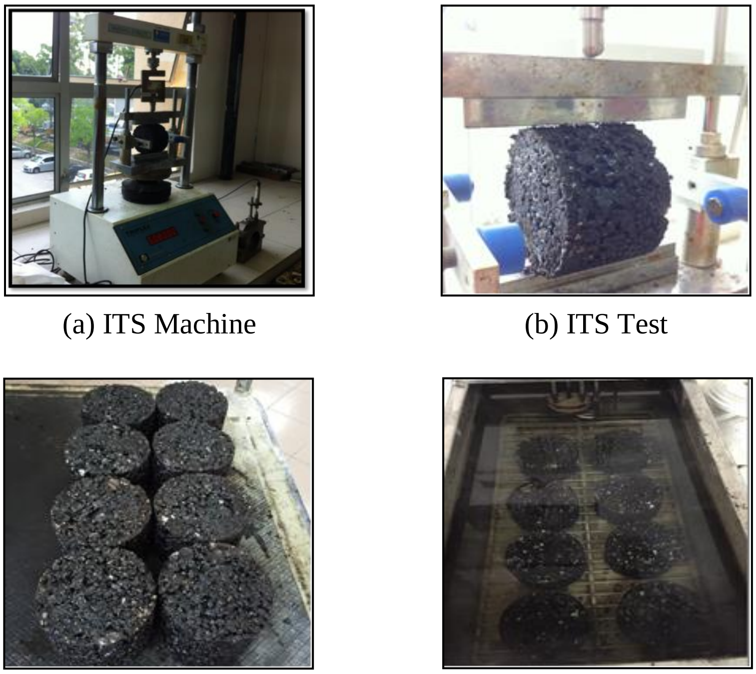
Lastly, the potential moisture induced damage for PA in accordance to its Tensile Strength Ratio (TSR) was obtained from Equation 2. TSR value will indicates the resistance of PA towards moisture damage. 80% TSR was used as the boundary between PA resistant and sensitive to moisture.



(a) ITS Machine (b) ITS Test

(c) Dry Subset (d) Wet Subset

Figure 1. Modified Lottman Test.

$$S_t = 2P/\mu Dt \quad (1)$$

Where: S_t = Tensile Strength (*KPa)*
P = Applied Load (*N)*
t = Thickness of Specimen (*mm)*
D = Diameter of Specimen (*mm)*

$$TSR = (S_{t\ wet}/S_{t\ dry}) \text{ X } 100 \quad (2)$$

Where: $S_{t\ wet}$ = Average Tensile Strength of Wet Conditioned Subset (*KPa)*
$S_{t\ dry}$ = Average Tensile Strength of Dry Subset in (*KPa)*

4. Results and Discussion

4.1. Indirect Tensile Strength

From Modified Lottman Test, the value of Maximum Applied Load (P) for every samples of PA was obtained, then this value was used to calculate the ITS and TSR values. From Figure 2, the highest ITS value for dry condition was at 6% NS-PA which was 477 KPa, followed by 4% NS-PA (450 KPa), 2% NS-PA (381 KPa) and the lowest value from control sample (0% NS-PA) which was only 298 KPa. The same trend also obtained from ITS value for wet condition, where the highest ITS at 6% NS-PA (388 KPa), followed by 2% NS-PA (347 KPa), 4% NS-PA (318 KPa) and again the lowest value was at 0% NS-PA (222 KPa). Theoretically, tensile strength indicates the cracking potential of PA, where higher tensile strength represents PA can withstand higher strain before failing, thus providing better crack resistant. From the ITS result, the value for wet condition samples were significantly lower compare to dry condition samples for every PA mix. This indicates that the existence of moisture reduce the tensile strength of PA, thus exposing the PA mix with cracking [11]. It is also proved that the existence of moisture affect the performance of PA.

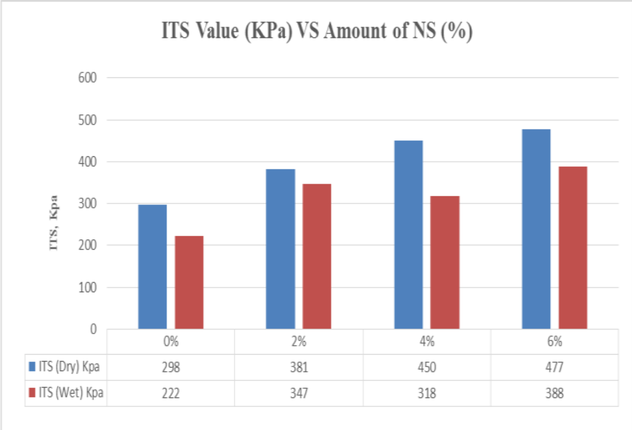


Figure 2. ITS value.

4.2. Tensile Strength Ratio

Tensile Strength Ratio is an essential indicator for PA whether PA can withstand moisture susceptibility or sensitive to it. Moisture susceptibility is also known as moisture induce damage or stripping. For PA, 70% TSR is acceptable due to its drainage capability. From Figure 3, the highest TSR value obtained at 2% NS-PA which was 91%, followed by 6% NS-PA 81%. For control sample (0% NS-PA) and 4% NS-PA, TSR value obtained were below 80% which were 74% and 71% respectively. But due to porous nature of PA, those value still acceptable. Thus, all the PA mix tested met the requirement and resist from moisture induce damage. Based on TSR value, the optimum amount of NS was 2%. It can be concluded that with proper concentration, the existence of NS in PA can significantly enhance the performance of PA especially in terms of moisture susceptibility [12]. This is due to NS dispersed well inside binder, strengthened the interconnecting bonds between binder molecules, thus enhancing the cohesion and adhesion properties of PA mix.

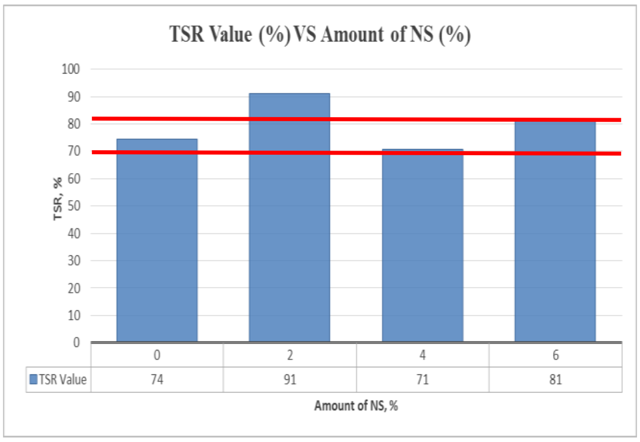


Figure 3. TSR value.

5. Conclusion
This study has highlighted that the application of nanosilica can significantly enhanced the performance of porous asphalt mixtures in terms of moisture susceptibility. The ITS test that was conducted proved that the addition of nanosilica improved the properties of porous asphalt. The ITS value for dry condition sample was higher compared to wet condition sample due to the effect of moisture inside the PA mixture. The properties of porous asphalt with the existence of Nanosilica are improved. From the result:

a) TSR value for every samples met the minimum requirement by AASTHOT283, thus indicates that PA design mix in this study was resist to moisture susceptibility.
b) From TSR value, 2% NS is the optimum amount that can enhanced the properties of PA in terms of moisture susceptibility with TSR value 91%.
c) With proper concentration, nanosilica was significantly enhanced the moisture induce resistance of PA.
d) Based on ITS value for NS-PA, the difference between wet and dry condition samples were insignificance, thus proved that Nanosilica was capable to provide PA with adequate resistance towards moisture damage.

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