Evaluation of moisture-induced damage of dense graded and gap graded asphalt mixture with nanopolymer modified binder

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Abstract. The purpose of this research is to study the moisture induce damage performance of dense graded (AC14) and stone mastic asphalt (SMA14) asphalt pavement using Nanopolyacrylate polymer modified asphalt binder. The physical properties of aggregate, volumetric and performance of asphalt mixes were assessed and evaluated with the laboratory tests. The study investigates fourteenth different asphalt mixtures consisting of NP modified asphalt binder formulations at 2%, 4% and 6%. Two types of asphalt binder, penetration grade PEN 80-100 and performance grade PG 76 were added with Nanopolyacrylate as asphalt modifier. The modified asphalt binder was prepared by adding 6 percent of Nanopolyacrylate (NP) to the asphalt binder. Both AC14 and SMA14 mixes passed the Marshall requirements which indicate that these mixtures were good with respect to durability and flexibility. In terms of moisture induce damage, it was observed that the strength of the asphalt mixes increased with the addition of NP polymer modified asphalt binder. Similar trend could also be seen for SMA14 mixes, where the ITS value of SMA14 showed a significant difference compared to AC14 and all the mixtures exceeded the minimum requirement value as specified in the specification. Thus, addition of nanopolyacrylate polymer to the asphalt binder has significantly improved the cohesion as well as adhesion properties of the asphalt binder, and hence the stripping performance. Therefore, it can be concluded that the nanopolyacrylate is suitable to be used as a modifier to the modified asphalt binder in order to enhance the properties of the asphalt binder and thus improving the performance of asphalt in both AC14 and SMA14 mixes.

1. Introduction
Moisture-induced damage is one of the most common distress in asphalt concrete pavements which normally occur due to increasing traffic volumes, truck traffic, higher tire pressures and environmental factors such as temperature, air and water. Moisture-induced damage is defined as the physical separation of the asphalt cement from the aggregate produced by the loss of adhesion between the asphalt cement and the aggregate which is primarily due to the action of water or water vapour [1]. The main mechanism of moisture induced damage in asphalt pavement is the loss of cohesion (strength) and stiffness of the asphalt film, and the failure of the adhesive bond between aggregate and asphalt in conjunction with the degradation or fracture of the aggregate[2].

Moisture-induced damage can also significantly increase the maintenance of road costs fuel consumption as well as reduce the service life of the pavement. These conditions has led to the
increased use and development of polymer modified asphalt binders due to poor performance of bituminous mixtures. Polymer modified asphalt binder (PMB) has been found to improve the resistance of asphalt pavement performance to stripping, rutting deformation, fatigue and low temperature cracking, wear resistance and ageing[3,4]. Many research had been conducted using different types of additives and modifiers such as NR (natural rubber latex), SBS (Styrene Butadiene Styrene Block Copolymer), SBR (Styrene Butadiene Rubber Latex), and EVA (Ethyl Vinyl Acetate), however, there are shortcomings such as low stability in using polymers. The addition of nanomaterials in asphalt pavement mixtures has the potential to enhance further the properties of asphalt mixes and overcome the shortcomings of using polymer in asphalt pavement mixes.

The use of nano-materials has seen a tremendous development in recent years mainly due to their surface properties and their effectiveness in altering hierarchical structure of composite materials [5, 6, 7]. Study by Yusoff on the potential benefits of nanosilica particles in asphalt mixtures concluded that asphalt mixture modified by 4% nanosilica enhanced the fatigue and rutting resistance and appears to have the greatest potential for beneficial modification of the binder[8]. Yao reported that addition of nanoclay and carbon microfiber improves the stripping performance mixtures or decreases the potential of moisture damage[9]. In this research, the use of nanopolyacrylate polymer as a modifier was investigated. The influence of modified asphalt binder using Nanopolyacrylate has not been explored in improving the properties of asphalt binder.

Previous studies have shown that the use of Stone Mastic Asphalt (SMA) mix improves resistance to rutting and also increases pavement durability compared to other types of asphalt mixture[10,11]. SMA for road pavement surfacing has been reported to increase the durability of the mixes thus providing high resistance to rutting. Previous studies on SMA also found that the SMA mixture is more resistance to rutting compared to dense graded asphalt mixtures[12]. This is attributed to the coarse aggregate skeleton as well as higher asphalt content while providing stone-on stone contact among the coarse aggregate.

The main purpose of this research was to determine the effects of using nanopolyacrylate polymer on the engineering properties of asphaltic concrete (AC14) and stone mastic asphalt (SMA14) mixtures and also to evaluate moisture-induced damage of polymer modified mix compared to control mix for both gradation. It is thought that the addition of NP to asphalt binder might offer an excellent potential for asphalt binder modification due to their inherent compatibility with asphalt cement and excellent mechanical properties. Therefore, in this research, a new asphalt binder based on nanopolyacrylate was investigated and characterized for possible improvements in the asphalt mix. It is believed that the nanopolyacrylate modified asphalt binder would offer better performing asphalt mixes and such study is worthwhile for a sustainable road infrastructure that will provide a long lasting, safe and comfortable ride for the road users.

2. Methodology

The study focused on the volumetric properties and stripping evaluation of Dense Graded (AC) and Gap Graded (SMA) Mix with Nanopolymer modified asphalt binder. The samples for control mix and modified mixes were prepared based on the Marshall Mix Design method in accordance with ASTM D1559.

2.1 Material properties.
Granite aggregates, nanopolyacrylate (NP) polymer, asphalt binder of PEN 80/100 and PG 76 asphalt binder are the materials used in this research. Granite aggregates were supplied by Blacktop Quarry, Rawang located in Klang Valley. Nanopolyacrylate was provided by the Nan Pao Resins Chemical CO., Taiwan and natural rubber latex was provided by MTD Group, Klang. The aggregates were processed by washing, oven drying and sieving. All the aggregates were sieved to the appropriate size and stored in individual bins according to the size and were tested according to physical testing aggregate standard requirement. Table1 below shows the aggregate properties result. The aggregates meet the aggregate properties requirement. Thus, the aggregates are acceptable and suitable for use in road works.
Table 1. Aggregate Properties

| Aggregate Test      | Specification | Result |
|---------------------|---------------|--------|
| Flakiness           | <20%          | 3.1%   |
| Elongation          | <20%          | 16.6%  |
| Aggregate Impact Value | <45%        | 21.75% |
| LA Abrasion         | <45%          | 25.35% |

2.2. Asphalt Binder Modification

The asphalt binder used in this study was 80/100 PEN for control sample while PEN 80/100 with nanopolyacrylate polymer was used for the modified sample. The modified asphalt binder was prepared by mixing control sample with a proportion of nanopolyacrylate. The most effective amount of nanopolyacrylate from previous studies was found to be 6% by weight of asphalt binder, where it has great potential to improve the physical properties and the performance of bituminous mix [13]. For the preparation of a sample, 500 g of base asphalt binder was melted at 110 °C and poured into a 500 ml container. Then, the asphalt binder was heated in the oven at 150 °C until it became liquid. The 4% nanopolyacrylate was added slowly into the liquid asphalt binder and was sheared with a high shear mixer with mechanical stirrer at selected blending velocity and time. Polymer modified Asphalt binder was then used for further physical properties testing in order to determine the optimum binder content.

2.3. Marshall Mix Design

The Marshall Mix design method was conducted to determine the volumetric properties and the optimum asphalt binder content. Marshall samples are prepared and tested according to JKR/SPJ/2008-S4 (Public Work Department of Malaysia, 2008) requirement and specification. In this study, AC14 and SMA14 mixtures prepared using NP polymer as a modifier in the asphalt binder. Figure 1 and 2 illustrates the aggregate gradation semi-log graph for percentage aggregate passing versus sieve size to the power of 0.45 for AC14 and SMA14 mix.

![Figure 1. Gradation Limit for AC14.](attachment:image)
A total of fifteen samples were prepared for both AC14 and SMA14 mixtures at different polymer content ranging from 4.5% to 6.5% for AC14 and 5% to 7% for SMA14. Marshall samples were weighed about 1200g and then heated prior to mixing and compacting process. All the AC14 Marshall samples were subjected to 75 blows/face compaction while the SMA14 Marshall samples were subjected to 50 blows/face of compaction. Results from the Marshall volumetric analysis were used to select the Optimum Binder Content (OBC) to form strong and stable mix. The volumetric properties determined included bulk specific gravity, air void, voids in mix (VMA), stability and flow. The Optimum Binder Content (OBC) for the control and modified asphalt mixes were determined from the individual plots of bulk density, voids in total mix, voids in mix, flow and stability versus percent asphalt content.

2.4. Moisture Susceptibility Test
Moisture susceptibility test procedures measures the loss of strength or stiffness of an asphalt mix due to moisture induce damage. The Modified Lottman test (AASHTO T283) was performed to verify that the design trial mix formulated is susceptible to damage by moisture in the pavement. This test is performed by compacting samples to an air void level of 7 ± 0.5%. Three samples were selected as a control and tested without moisture conditioning; and another three samples were selected to be conditioned by saturating with water at 70-80 percent followed by immersing in water for 24 hours at 60ºC in a water bath. The samples were then tested for indirect tensile strength (ITS) by loading the samples at constant head rate (50 mm/minute vertical deformation at 25ºC) and maximum compressive force required to break the sample were recorded. Tensile Strength Ratio (TSR) results were determined by comparing the indirect tensile strength (ITS) of unconditioned samples with the control samples. The Tensile Strength ratio (TSR) values in the test are an indication of the potential for moisture damage. Higher TSR value indicates greater resistance of the mix to moisture damage. Retained tensile strength ratio (TSR) was used with 80% as the boundary between mixtures resistant and sensitive to moisture.

3. Result and discussion

3.1. Marshall Volumetric Properties and determination of optimum binder content.
Table 2 and Table 3 presents the optimum binder content (OBC) results and their volumetric properties for both AC14 and SMA14 mixes used in this study. It was found that both volumetric properties of AC14 and SMA14 mixes meet the JKR specification requirement. OBC from Marshall Mixture design method for dense graded-AC14 mix was found to range from 5.2% to 5.6% and OBC
for gap graded-SMA14 mix ranged from 6.3% to 6.7%. The result shows that the OBC value of SMA14 mix was higher than AC14 mix. This could be due to the absorption of asphalt with the high filler material in SMA14 mix which increased the binder content needed. The results also showed that different types of gradation between AC14 and SMA14 have significant effect on the stiffness. As can be seen in Table 3 and Table 4, the gap graded SMA14 asphalt mixes have lower Marshall Stability compared to dense graded AC14 asphalt mixes. It can be concluded that the addition of nanopolyacrylate tend to increase the stiffness of AC14 and SMA14 compared to control mix due to the elastic behaviour of the nanopolyacrylate added. The finding of the study by Hainin et al., (1995) and Hainin et al., (2013) supported that modifying AC14 asphalt mixture enhances Marshall properties better than SMA14 mixture especially in stability and stiffness of the mixture[1,13]. From the data obtained, it is concluded that, all the AC14 and SMA14 volumetric properties met the JKR specifications and hence all the mixtures were further evaluated for performance tests.

### Table 2. Control and Polymer Modified Asphalt Binder Mixtures of Marshall Mix Design Results of AC14

| Mixture type Dense Graded (AC14) | AC14- Control | AC14- NP2 | AC14- NP4 | AC14- NP6 | Specification (JKR/SPJ/ 2008-S4) |
|---------------------------------|---------------|----------|----------|----------|----------------------------------|
| Polymer content (%)             | 0             | 2        | 4        | 6        |                                  |
| OBC (%)                         | 5.2           | 5.3      | 5.5      | 5.6      |                                  |
| Stability (kg)                  | 1120          | 1170     | 1270     | 1298     | >815                             |
| Flow (mm)                       | 3.56          | 3.46     | 3.35     | 3.28     | 2.0-4.0                          |
| Stiffness (kg/mm)               | 314           | 341      | 382      | 392      | >203                             |
| VTM (%)                         | 3.6           | 3.8      | 4.2      | 4.4      | 3.0-5.0                          |
| VFB(%)                          | 77            | 74.5     | 74       | 73.5     | 70-80                            |

### Table 3. Control and Polymer Modified Asphalt Binder Mixtures of Marshall Mix Design Results of SMA14

| Mixture type Gap Graded (SMA14) | SMA14- CONTROL | SMA14- NP2 | SMA14- NP4 | SMA14- NP6 | Specification (JKR/SPJ/ 2008-S4) |
|---------------------------------|----------------|-----------|-----------|-----------|----------------------------------|
| Polymer content (%)             | 0              | 2         | 4         | 6         |                                  |
| OBC (%)                         | 6.7            | 6.6       | 6.5       | 6.3       | MIN 6 (AASHTO)                   |
| Stability (kg)                  | 970            | 742       | 840       | 955       | >632                             |
| Flow (mm)                       | 3.0            | 3.6       | 3.34      | 2.89      | 2.0-4.0                          |
| Stiffness (kg/mm)               | 324.5          | 210       | 256       | 338       | NONE                             |
| VTM (%)                         | 4.1            | 4         | 4.1       | 4.2       | 3.0-5.0                          |
| VMA(%)                          | 19.1           | 19.3      | 19.4      | 19.6      | MIN 17                           |
| Drain down (%)                  | 0.25           | 0.26      | 0.24      | 0.21      | <0.3                             |

3.2 Moisture Susceptibility

The tensile strength is an indicator of cracking potential. A higher tensile strain at fracture indicates that a particular HMA can tolerate higher strains before failing, which more likely to resist cracking than HMA with a low tensile strain at failure. If the water-conditioned tensile strength is relatively high as compared to the dry tensile strength, the HMA can be considered as reasonably moisture resistant. Figure 3 shows the result of moisture susceptibility test for both AC14 and SMA14 mixtures. In dry condition, the SMA14 mixtures strength values varies from 355 kPa to 642 kPa compared to AC14 mixtures which exhibit higher strength values ranging from 500 kPa to 511 kPa. The results show that the dry samples for AC14 mixture with 6% NP gave the highest tensile strength (642KPa). In wet conditioned, the tensile strength (IDT) results showed similar trend to the dry conditioned samples which showed the SMA14 mixture with 6%NP has the highest tensile strength values (511 kPa). From the result, the tensile strength (IDT) of AC14 mixtures is slightly greater than SMA14 mixtures. Similar
results were also reported that dense graded mixes (AC14) have higher tensile strength than open graded mixes (SMA14). This is due to the higher air void of SMA14 mixes causing the mix to have higher deformation and lower strength[15]. In wet conditioned, the tensile strength (IDT) of wet conditioned sample are lower than the dry conditioned samples tensile strength (IDT) values. This shows that the moisture (wet conditioned sample) will decrease the value of indirect tensile strength. This finding indicates that there is deterioration in the mixtures which affects the strength of the HMA mixes and thus reduce the tensile strength of the mixtures.

![Figure 3. Indirect Tensile Strength of Dry Conditioned and Wet Conditioned Samples for AC14 and SMA14 Mixes](image)

The tensile strength ratio (TSR) result is an indication of the asphaltic mix is susceptible to moisture damage. Figure 4 showed that the TSR for all the AC14 and SMA14 mixes. The TSR value for mixtures with AC14-Control, AC14-NP2%, AC14-NP4% and AC14-NP6% are 82.2%, 86.3%, 87.2% and 93.1% while the TSR value for SMA14 mixtures with 2%, 4% and 6% NP content are 84.2%, 90.1%, 91.4% and 96.4% respectively. When comparing the tensile strength ratio (TSR) for AC14 and SMA14 mixtures, it was found that the AC14 and SMA14 demonstrate great potential in improving moisture damage. Although TSR values are generally higher for other mixes compared to control mixes, this does not mean that other mixes are less susceptible to moisture damage. The results obtained indicate that the TSR ratio for both AC14 and SMA14 mixes fulfilled the AASHTO T283 criteria which indicate that both mixes are resistant to moisture damage and could sustain the load from vehicles when exposed to severe condition without large degradation of the structure.
4. Conclusion
In this study, the volumetric properties of Marshall mix design and moisture, induce damage performance of the mixes were evaluated to determine the resistance of AC14 and SMA14 asphaltic mixtures. Based on the results obtained from this study, the following conclusions have been reached:

i. The addition of Nanopolyacrylate polymer in asphalt mixture was found to be significant, where nanopolyacrylate has enhanced its stripping resistance due to greater elasticity offered by the nanopolyacrylate particles. The addition of Nanopolyacrylate influence the stripping behaviour of the mixture; hence increasing the Tensile Strength Ratio (TSR) of the mixes; the increase in the NP content increased the stripping resistance. However, all mixes are resistant to moisture damage.

ii. Nanopolyacrylate polymer can be used as modifier in both AC14 and SMA14.

iii. Nanopolyacrylate polymer appears to improve the stripping resistance due to insignificant difference between the unconditioned and conditioned results for modified mixes.

iv. The AC14 and SMA14 using nanopolymer modified asphalt binder demonstrate great potential in improving moisture damage. The results obtained indicate that the TSR ratio for both AC14 and SMA14 mixes fulfilled the AASHTO T283 criteria which indicate that both mixes are resistance to moisture damage and could sustain the load from vehicles when exposed to severe condition without large degradation of the structure.

Thus, the addition of nanopolyacrylate polymer to the asphalt binder in both dense graded and gap graded asphalt mixture has significantly improved the cohesion as well as adhesion properties of the binder, and hence the performance of the mix to moisture-induce damage.

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