Characteristics of Pavement Materials Treated with Polyacrylamide-Based Additive

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Abstract

Polymer additives have shown to improve strength and durability characteristics of granular and subgrade pavement materials. This is in addition to their advantage of lower carbon footprints compared to traditional cementitious additives. This study reports the outcomes of a laboratory investigation to evaluate the use of a polymeric stabilization technique in improving engineering properties of pavement foundation materials. A synthetic polyacrylamide-based additive (PAM) has been used to stabilize three types of soils, commonly used in pavement construction. The stiffness characteristics of PAM-treated soils have been analysed by conducting repeated load triaxial tests. Simple capillary rise and abrasion tests have also been carried out in order to assess durability characteristics of stabilized materials. The results have shown a significant overall increase in resilient modulus for the treated samples, with varying levels, depending on soil type. Further, the PAM used herein enhances the sealing capacity of the soils with the rise of a water table. Additionally, dramatic improvements in abrasion resistance have been recorded for all the soils tested herein, which makes them suitable for use in wearing courses of unsealed pavements.

Key Words: Polyacrylamide based additive, Repeated load triaxial, Abrasion test, Durability.
Introduction

Local, State and Federal governments are under pressure to design, build and maintain road infrastructure within the conservative funds available. This is in addition to balancing the increasing demand of high performance roads on one hand, and the increasing social awareness of associated environmental impacts and the preservation of scarce natural resources on the other hand. Therefore, attention has been paid to the use of low quality materials and innovative construction techniques to provide a potential good performance in a cost-effective way. Stabilization has been found to be an innovative technique that helps to prolong the service life of pavement, and potentially reduce the thickness of structural base or subbase layers hence, provides a more economical design. Therefore, the development of non-traditional stabilizers, such as polymers have gained greater attention as they demonstrate effectiveness in the field with regards to reducing permeability, increasing durability, and non-time dependence of mixing and compaction, as well as better sustainability outcomes (Andrews and Sharp, 2009, Wilmot, 1994, Andrews and Sharp, 2010, Camarena, 2013).

Polymeric-based additives have been used in the stabilization of unsealed pavements as well as granular materials of select fills (working platforms over weak subgrades) and subgrades for sealed pavements to enhance performance properties. However, very few studies have been carried out to assess the feasibility of using PAM stabilized granular materials in pavement structural layers (base and subbase). This aim of the study reported herein is to evaluate the suitability of using PAM-treated granular materials that are currently used in wearing courses of unsealed pavements in subbase layers of sealed low volume road pavements. To achieve the aim of this study, a laboratory experimental program has been undertaken to assess the changes in stiffness and durability characteristics of pavement materials when treated with an off the shelf synthetic polyacrylamide-based stabilizing additive. The tests performed include repeated load triaxial test (RLT), capillary rise and abrasion tests. The outcomes of this study will contribute to improving the knowledge regarding the behaviour of PAM-treated materials within a pavement structure and help promote the reliability of these sustainable materials for wider adoption by road authorities.

Materials and Methods

Three different soil samples from three different sites in Victoria/ Australia were selected for this study, denoted as soil I, II and III. The soil samples were collected from the top 150 mm of existing wearing courses of several unsealed roads that were being stabilized with PAM. For the three soil types, plasticity
indices were determined following Australian standard AS 1289.3.3.1 (AS, 2009) and their classifications were determined using the unified soil classification system (USCS) (ASTM, 2011). The classification and geotechnical properties of the tested soils are summarized in Table 1.

The polymeric additive used in this study was a synthetic soluble anionic PAM, which is produced in a granulated form. This PAM a non-toxic water soluble material with a specific gravity of 0.8 and a PH value of 6.9 at 25 °C, and has a high molecular weight typically between 12 and 15 Mg/mole.

For samples preparation, the PAM amount used was 0.002 % by dry weight of the soil, according to supplier’s recommendation. The PAM was first mixed with water in a sealed container at a rate of 2 grams per 5 litres, which created a polymer concentration rate that was twice the recommended rate. This concentrated solution was then dissolved further to match the required moisture requirement for the soil sample. The soil-water mixture was then mixed in a mechanical mixer for 10-15 minutes.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Soil I</th>
<th>Soil II</th>
<th>Soil III</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Gravel (19.0-4.75 mm)</td>
<td>33.2</td>
<td>29.6</td>
<td>13.2</td>
</tr>
<tr>
<td>% Sand (2.36-0.075 mm)</td>
<td>56.8</td>
<td>46.4</td>
<td>36.8</td>
</tr>
<tr>
<td>% Fines (&lt; 0.075 mm)</td>
<td>10.0</td>
<td>24.0</td>
<td>50.0</td>
</tr>
<tr>
<td>% Clay</td>
<td>1.0</td>
<td>2.75</td>
<td>13.5</td>
</tr>
<tr>
<td>Liquid limit (%)</td>
<td>22.2</td>
<td>23.8</td>
<td>31.4</td>
</tr>
<tr>
<td>Plastic limit (%)</td>
<td>N/A</td>
<td>12.8</td>
<td>15.1</td>
</tr>
<tr>
<td>Plasticity Index (%)</td>
<td>N/A</td>
<td>11</td>
<td>16.3</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2.78</td>
<td>2.51</td>
<td>2.65</td>
</tr>
<tr>
<td>Water absorption (coarse fraction), %</td>
<td>2.19</td>
<td>11.26</td>
<td>2.46</td>
</tr>
<tr>
<td>Optimum Moisture Content (%)</td>
<td>5.6</td>
<td>8.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Max Dry Density (g/cm³)</td>
<td>2.35</td>
<td>2.01</td>
<td>1.95</td>
</tr>
<tr>
<td>Soil Classification, (USCS)</td>
<td>Poorly-graded Sand with Silt (SP-SM)</td>
<td>Clayey Sand with Gravel (SC)</td>
<td>Sandy Clay (CL)</td>
</tr>
</tbody>
</table>

The maximum dry density and optimum moisture content were then determined, for treated and untreated samples, using the Australian modified proctor compaction test (AS, 2003). The samples were compacted in five layers but the standard compaction effort of 25 blows per layer (i.e. 2,703 kNm/m³) was changed to 45 blows per layer (i.e. 4,961 kNm/m³) for soil type I, and 35 blows per layer (i.e. 3,868 kNm/m³) for soil types II and III. These compaction efforts were found to be the optimum for each soil type and were determined after a number of trials to ensure that laboratory performance of PAM-treated
samples was comparable with relevant observed field performance. Thereafter, this variation in compaction energy was applied to both treated and untreated samples.

RLT test was conducted in accordance with the recommended Australian test procedure (Austroads, 2007). The specimens were prepared in split moulds of 100 mm in diameter and 200 mm in height and were compacted in 8 layers using proctor compactor at a compaction effort corresponding to the soil type. All specimens were compacted to the target density of 100% maximum dry density (MDD) at the optimum moisture content (OMC). After compaction, specimens were removed carefully from the split moulds and left to dry back to 50% of OMC.

The resilient modulus determination characterizes the vertical resilient strain responses over 66 stress conditions at 200 cycles per condition, and a combination of applied repeated vertical (deviatoric) and static lateral (confining) stresses ranging from 100 to 600 kPa and 20 to 150 kPa, respectively. The increments of the stresses and stress ratios were small to avoid early failure, which can occur at high stress ratios (Austroads, 2007, AASHTO, 2003). In all test conditions, none of the specimens underwent damage due to cyclic loading. For each combination of deviatoric and confining stresses the resilient modulus was determined using the following equation:

\[ M_R = \frac{\sigma_d}{\epsilon_r} \]  

(1)

Where, \( M_R \) is resilient modulus; \( \sigma_d \) is the deviatoric stress; and \( \epsilon_r \) is the recoverable strain.

In this study, the abrasion resistance test was performed according to the test method proposed by Sampson (1988). Here, soil samples were sieved to collect only particles less than or equal to 4.75 mm in diameter. The reason for selecting maximum aggregate size of 4.75mm was to eliminate the possibility of intermittent plucking of the coarse particles by the brush, which eliminates a continual loss of mass with increased revolution (Jones, 2007). Test samples were prepared according to the procedure outlined earlier for the modified proctor compaction test and using relevant optimum compaction efforts. The specimens were then left to dry back until reaching a constant mass. At least three specimens per sample (treated and untreated) were prepared. The cylindrical specimens were tested by subjecting 500 revolutions of the brush load of 2.2 kg to the side of the specimen, as shown in Fig. 1, over two stages of 250 revolutions to reproduce the long term traffic wear action in the laboratory (Sampson, 1988). The brushed specimens were then weighed and the loss of mass as a percentage of the original mass was recorded.
The capillary rise test was performed according to the Australian standards AS 1141.53 (AS, 1996). Specimens of soil type II were prepared by mixing the soil samples in dry conditions with the predetermined optimum water content. This soil type was chosen because of its high porosity compared to the other two soil types (i.e. soils I and III). The samples were then kept in sealed plastic bags for 24 hours in a storage room with a temperature of 20ºC ± 2 to allow even moisture distribution. The mixture was then placed in moulds (105 mm diameter and 116 mm height) and compacted in five layers using relevant optimum compactive energy of 3,868 kNm/m³. Then the specimens were allowed to dry back to a constant mass, after which they were placed in water at room temperature in a dish to a depth of 20 mm. Capillary rise measurements were taken at different time intervals.

**Results and Discussion**

**Stiffness Characteristics**

*Resilient Modulus (MR) Test Results*
To successfully characterize flexible pavement materials using a mechanistic approach, resilient modulus values obtained from repeated load testing are required (AASHTO, 1993, Jameson, 2006). For each of the 66 stress stage, of RLT test, which consists of one value of confining stress and a corresponding deviatoric stress, the resilient modulus ($M_R$) values were determined for treated and untreated samples of the three soil types and plotted in Fig. 2. Fig. 2 presents the variations of confining pressures and corresponding deviatoric stresses together with associated $M_R$ values over the 66 stress stages of the RLT test. With careful examination of the figure, the following could be observed:

- The resilient moduli for all three soil types are considerably affected by both deviatoric and confining stresses. Generally, $M_R$ values over the 66 stress stages of all soil types increase with confining pressures and deviatoric stresses.
- The addition of PAM to the soils enhances the values of their resilient moduli over all 66 stages of stress conditions.
- The differences in $M_R$ values of treated samples from untreated, for the three soil types, also vary with the magnitude of confining pressures. Soil type I shows higher differences at high confining pressures, while higher differences for soil types II and III are found at lower confining pressures.
- A maximum difference between untreated and PAM-treated samples for soil type I is 31.9 %. Soil type III, on the other hand, has shown a maximum increase in the $M_R$ values for the PAM-treated specimens at 46 % when compared with the untreated counterparts. However, the maximum difference in $M_R$ between treated and untreated samples for soil type II is only 8 %.
To better observe the effect of PAM additive on the resilient properties, a comparison was conducted between the average $M_R$ values at a certain stress stage i.e. deviatoric and confining stresses.
Here, average $M_R$ values were determined at 100 kPa deviatoric stress and 20 kPa confining pressure which simulate a stress level closest to in-situ stress level for a subbase layer, as recommended by Virgil Ping et al. (2001). The results show that the impact of PAM on $M_R$ value is more pronounced in treated samples of soil type III with 55.8 % increase over that of the untreated samples. Soil type I also exhibits a significant increase in $M_R$ when the samples were treated with PAM with an average increase in $M_R$ of 35 %. However, treated samples of soil type II show a limited increase in average $M_R$ value of 8.8 % only over that of untreated samples. It is believed that soils with high porosity (i.e. high water absorption, see Table 1) need more PAM concentration and longer curing time for satisfactory adsorption of PAM onto the soil surfaces to strengthen the binding between aggregate particles.

**Durability Characteristics**

*Abrasion Resistance Test Results*

For layers before being overlaid, consideration should be given not only to stabilize a material to enhance strength characteristics, but also to provide a seal to the compacted subgrade and/or granular layer to resist abrasion due to construction traffic and also to resist water erosion in case of rainy condition. Fig. 3 demonstrates the effect of PAM on increasing the abrasion resistance of the treated soils using the abrasion test. It is worth noting that the mass losses (in grams) for the samples (treated and untreated) presented in this figure are the average values of at least three specimens per sample.

![Graph](image)

**Fig. 3.** Abrasion resistance test for the treated and untreated samples of soils I, II and III
Fig. 3 clearly shows that there is an increase in the mass loss for all soil types when the materials are subjected to higher brush load revolutions. For the first 250 revolutions of abrasion, the mass loss is greatest for soil I and least for soil II. The mass loss is strongly dependent on the soil type (i.e. the amount of clay fines present in the soil), and the abrasion resistance was highest for soil type III followed by soil type II and soil type I. This is supported by the role of clay in increasing the cohesion of materials. This trend is true for both treated and untreated soils, but less intensity was identified in the treated samples. Fig. 3 also demonstrates a regular increase in abrasion resistance for the treated samples when compared to the untreated samples. Abrasion resistance, at the end of 250 revolutions, is dramatically increased in the treated samples of soils I and III with an average of 45.1 and 60.9 %, respectively. Whereas soil II only showed a 38.1 % increase in abrasion resistance. On the other hand, increasing the brush load revolution to 500 did not change the trend and the mass loss for soils I, II and III was 48, 23.5 and 59.3 %, respectively.

It is believed that the adsorption of anionic PAM onto the clay particles occurs by cation bridging (Theng, 1982), through which the polyvalent cations bridge the negative charged groups of clay particles and polymers together. On the other hand, bonding between particles is increased essentially by dual process: First, slipping action of PAM in the compaction stage, resulting in increased density and hence, increased contact points per unit area between the soil particles; second, PAM molecular encapsulates the soil particles and upon drying an electrostatic attraction among soil particles is provided. These dual actions made treated materials to exhibit stronger bond and less mass loss.

Capillary Rise Test Results

As mentioned earlier, capillary rise tests were conducted on treated and untreated samples of soil type II. The percentage water rise for treated and untreated samples of soil II is presented in Fig. 4. It is worth noting that these results are the average of three specimens per sample (treated and untreated). The figure shows that water rise speed of untreated samples is distinctly different from that of treated samples. The average speed of water rise through the untreated specimens reached 18.7 mm/hour in the first four hours, while in the treated specimens, the average speed of water rise was approximately 8.9 mm/hour. Further, after 48 hours, the capillary moisture of untreated specimens was near the top of the specimen, while the PAM- treated specimens had the capillary rise up to 40% of the total specimen height. The amount of water that can move upward in the stabilized specimen maintained the same level after 120 hours, while
the untreated specimens were fully covered with moisture. Fig. 5 shows the specimens (untreated and PAM treated) at the completion of the tests.

Fig. 4. Percentage water rise in treated and untreated samples of soil type II

Fig. 5. Capillary rise test; (a) untreated specimen after 48 hours period, (b) treated specimen after 120 hours period
As a matter of fact, capillary energy is a function of the liquid properties along with soil properties. In other words, if soil properties are kept constant, increased liquid wettability (e.g. contact angle with pore aggregate surface) and increased liquid surface tension will increase the capillary suction in the soils. However, in the case herein, when PAM is in contact with water, the solution’s viscosity becomes higher, resulting in increasing the time of contact between water and soil particles (Malik et al., 1991), thereby the absorption time for the whole sample will increase. This action can be called the “external waterproofing”, rather than internal waterproofing.

Conclusions

From the results of this study, the following could be concluded:

1- The addition of PAM increased the resilient modulus for the granular soils tested herein as well as the cohesive soil by at least 31 and 46 % respectively, when compared to corresponding untreated samples. The percentage increase in resilient modulus was not significant in a Clayey Sand soil (soil II), which showed approximately 8 % increase.

2- An increase in the resistance to abrasion was measured between 29.2 and 62.5 % for all soil types treated with PAM. There was no evidence that soil type was a factor.

3- Using PAM additive as a stabilizing agent has shown to reduce the capillarity action of soil. Samples treated with PAM showed capability of reducing the rising water speed to 60 % in the first four hours of the test.

Overall, these results indicate that PAM is a viable alternative additive for sustainably improving the performance of pavement foundation materials with a potential of reducing pavement thickness. Their usage in pavement foundation applications will also significantly lower the carbon footprint for future road infrastructure construction and maintenance by utilizing this material as an alternative to traditional cementitious materials.

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