Improving the Durability of Open Graded Asphalt

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Abstract

Open graded asphalt is a highly porous friction course utilised on high-speed roadways, due to its ability to reduce water spray and traffic noise. These functional characteristics have shown to deteriorate over time, reducing the durability of this pavement course. International research has demonstrated the effectiveness of polymer modified and crumb rubber bitumen, fibre additives, two-layer asphalt and maintenance techniques at improving durability. This study has investigated the effectiveness of varying bitumen content, type and fibres of the existing gradation and also on mixtures with an altered aggregate gradation.

1.0 Introduction

Open graded asphalt (hereafter OGA) is utilised by Main Roads Western Australia to improve the surface characteristics of high-speed roads. The current mix design was developed in the late 1970's and whilst demonstrating many advantages, has shown to have a significantly reduced lifetime than alternate pavement surfaces. An increased lifetime would lead to less required replacement and maintenance of OGA, enabling reduced budget expenditure. Thus, MRWA may be enabled to satisfy their purpose of enhancing the community, through reduced socio-economic costs from lesser impact of maintenance on the community and increased road safety.

This project has therefore investigated methods to improve the durability of OGA to increase its service life and lifetime of its functional characteristics. This has been done through a review of international research in improving the functional properties of OGA. Based on this research this project has also endeavoured to develop a new OGA mix, through laboratory testing, with better functional characteristics. New mix designs have been trialled by altering the binder content, binder type and additives of the current mix, as well as altering the mix gradation.

1.1 Open Graded Asphalt

OGA is utilised as a wearing course on roadways due to its ability to improve the surface characteristics of high-speed roads. OGA is characterised by a large percentage of air voids, 18–25%, resulting from its coarse gradation. OGA derives stability from aggregate particle interlock, also allowing for drainage through its open structure (Austroads & AAPA, 2002).

1.1.1 Advantages of Open Graded Asphalt

The functional characteristics of OGA, namely low surface noise and reduced water spray in wet weather, result from its porous nature. The interconnected nature of air voids in OGA allows both horizontal and vertical drainage through the pavement course, reducing water spray and potential for aquaplaning. The porous structure allows improved visibility and reduced headlight glare allowing for improved safety. The coarse texture of OGA improves the adhesion between the tyre and road surface providing good skid resistance at high speeds and also during rainfall (ARRB, Austroads & AAPA, 2002, Kandhal, 2001, Takahashi, Poulikakos & Partl, 2003).

The open structure of porous asphalt and coarse surface macro texture allow a reduction in traffic noise generated at the road-tyre interface, by reducing air-pumping and absorbing noise (Takahashi, Poulikakos & Partl, 2003). Stone-on-stone contact between aggregate particles allows porous asphalt to be highly resistant to rutting of the surface. OGA has also shown to have good fatigue resistance, particularly when manufactured with PMBs or fibres. The functional characteristics bring about improved road safety for drivers, as well as improving the comfort of road users through noise reduction (ARRB, Austroads & AAPA, 2002).

1.1.2 Disadvantages of Open Graded Asphalt

The porous structure has also shown to be disadvantageous, allowing the introduction of water and air resulting in rapid binder hardening and aging. Over time these actions can cause the stripping of binder from the aggregate surface, suggested to further induce the course's ravelling potential. Ravelling of aggregate from the pavement course has shown to be particularly problematic at intersections and other adverse geometric locations due to the course's low shear resistance. The open structure of OGA also facilitates binder drainage during construction and placement, reducing binder film thickness on aggregate particles. The functional properties of OGA have shown to deteriorate over time due to stripping of aggregate, ravelling and clogging of air voids by debris (Takahashi, Poulikakos, & Partl, 2003, ARRB, Austroads & AAPA, 2002).

2.0 Summary of Literature Review Findings

2.1 Durability of Open Graded Asphalt

The durability of OGA is defined in terms of the durability of its functional characteristics and is measured relative to the performance of dense graded asphalt. OGA has been criticised as having poor durability, evidenced by its poor resistance to ravelling, the progressive disintegration of the asphalt surface due to dislodging of aggregate particles and loss of binder. Ravelling is suggested to be a consequence of insufficient bitumen content, caused by binder drain down. The porous nature of OGA makes it particularly susceptible to ravelling due to the accessibility of air, water and loose particles to interior air voids (Austroads & AAPA, 2002).

There are varying experiences with the durability of OGA courses internationally; however it is accepted amongst researchers that the service life of OGA is much less than dense graded asphalt, respectively 7-10 years compared to 8-25 years (Austroads & AAPA, 2002). Differences amongst researchers may be attributed to the differing mix designs, binder contents, aggregate gradations, binder types, materials, wearing course thicknesses and measuring devices.

2.2 Methods to Improve the Durability of Open Graded Asphalt

2.2.1 Polymer Modified Bitumen

An increasing trend to improve the durability of OGA, is the inclusion of polymer modified bitumens (hereafter PMBs) to the porous asphalt mix (Nielsen, 2006). PMBs have an increased viscosity allowing them to provide sufficient binder film thickness, thus reducing susceptibility to binder aging, suggested to lead to ravelling. Modified binders also improve mix behaviour and durability through consistency, toughness and stiffness, reducing initial stone loss from the OGA course (Voskuilen, Tolman & Rutten, 2004). These properties allow a reduction, and suggested elimination, of binder drainage through the pavement course (Austroads & AAPA, 2002). Studies by Faghri & Sadd (2002) showed the use of SBS modified binder in OGA mixtures approximately doubled its strength and permeability and increased air voids.

2.2.2 Crumb Rubber Bitumen

Crumb rubber binders behave similarly to PMBs and are produced by blending shredded, recycled vehicle tyres with bitumen. Rubber bitumen exhibits high cohesion, flexibility and creep resistance, also having a higher resistance to aging, due to antioxidants contained in rubber particles. Rubber bitumen provides an environmentally friendly solution to improve durability, as it makes use of recycled materials (Sainton, 1990).

2.2.3 Fibre Additives

Fibre additives reduce the tendency for binder drainage, inherent of OGA courses, allowing sufficient binder film thickness. The use of fibres combined with PMBs is suggested to optimise mix durability leading to reduced abrasion loss and increased durability (Mallick et al., 2000).

2.2.4 Two Layer Asphalt

The use of two-layer OGA is also claimed to improve functional durability through the combination of a fine upper course, filtering pollution and clogging, with a coarse lower course, providing noise reducing characteristics (Takahashi, Poulikakos, & Partl, 2003).

2.2.5 Maintenance

The use of maintenance to improve the durability of open graded friction courses differs from other methods of redesigning the OGA mix, rather endeavouring to extend its functional life or at best reinstate improve its service life. Maintenance techniques are generally designed around removing detritus from clogged voids, however methods also exist to reinstate the ravelling resistance of porous asphalt courses. Experience with maintenance is mixed, with the validity of some research compromised due to sponsorship by manufactures of the technology.

Other methods to improve durability include ensuring aggregate particles maintain stone-on-stone contact (Nielsen, 2006), specifying air voids (Kandhal, 2001), permeability, strength and temperature (Faghri & Sadd, 2002) and the use of warm mixtures (Soto & Blanco, 2004).

3.0 Experimental Design and Methods

3.1 Experimental Mixture Design

The mixture designs tested in the laboratory have been devised to improve the functional durability of the current, MRWA specified, mix, based on international research. Experiments have been carried out on mixtures with the existing gradation with varying bitumen contents, types and fibre additives and also on mixtures with an altered aggregate gradation.

3.1.1 Variations of Current Mixture Design

Laboratory testing was initially carried out on the current mix design, so that these results may be used as a benchmark against which other mix designs may be measured.

Fibre additives are suggested by Faghri & Sadd (2002) to improve durability, by reducing tendency for binder drainage. Fibre additives were hence added to mixes of comparable binder contents and type. The specified binder content by MRWA is 4.5% ± 0.3%. To investigate the effect of binder content on mix durability binder content was increased to 4.8% (1 tolerance) and 5.1% (2 tolerances). The effect of binder type was evaluated through the use of 170, unmodified bitumen. International literature highlighted the ability of PMBs in improving durability; hence the use of elastomeric (A20E) and plastomeric (A30P) PMBs. Similarly advantages highlighted by literature of crumb rubber bitumen warranted their inclusion. Fibres were added only to the PMB mix with the lowest particle loss, as PMBs themselves are said to reduce binder drain down. The 14 mixes tested in this phase were: 320 @ 4.5%, @ 4.5%+fibres, @ 4.8%+ fibres and @ 5.1%+fibres, 170 @ 4.5%, @ 4.5%+fibres, @ 4.7%+fibres and @ 4.9%+fibres, A20E @ 4.5%, @ 4.7% and @ 4.9%, A30P @ 4.5%, rubber @ 4.5% and A20E @ 5.2% + fibres.

3.1.2 Alternate Gradation Mixture Design

Research by Mallick et al. (2000) investigated the effect of aggregate gradation on OGA durability, requiring no more than 20% of material pass 4.75mm sieve to achieve stone-on-stone contact and provide adequate permeability. Therefore 70/30 and 80/20, more single sized mixes, and 14mm mixes have been trialled. It was also that found these mixes are more susceptible to binder drain down, thus the inclusion of fibres to these mixes. These mixes were produced using 320 bitumen, to ensure comparability with previous testing, at 4.8%, as larger gradations will have less surface area than the standard mix. Mixes tested included: 70/30 320 @ 4.8%+fibres, 80/20 320 @ 4.8%+fibres and 14mm 320 @ 4.8%+fibres.

3.2 Experimental Apparatus and Procedures

Each laboratory mix was produced by mixing aggregate, hydrated lime, fibres (if added) and bitumen, which were then conditioned in an oven. The mix was then quartered tray to obtain representative samples for the particle size distribution and Rice density test and scooped in to 6 Marshall moulds, compacted for further testing (as per AS2891), with remaining mix used for the binder drain down test.

The binder drain down test was carried out as per AG:PT/T235 and is suggested to illustrate the separation of binder from aggregate during transportation. The Rice density test (WA732.2) determines the maximum density of asphalt by water displacement. The particle size distribution and bitumen content test (WA730.1) were carried out using the centrifuge method, removing bitumen from the asphalt sample. A particle size distribution is then conducted on the aggregate using sieve analysis. A bulk density test was also conducted (WA 733.1) through measurement of the Marshall specimen's dimensions, used to determine air voids. The Corelok vacuum sealing method was also used to measure the Marshall specimen's air voids (WA733.2).

WA731.1 specifies the testing procedures for stability, the maximum load a specimen is able to withstand and flow, vertical deformation of the test specimen due to force application. A resilient modulus test (AS2891.13.1) was also carried out utilising an indirect tensile method, measuring the mechanical response of the pavement to load. Lastly particle loss tests (AG:PT/T236) were conducted on two conditioned (immersed in water for 20 hours to represent aging) and two unconditioned Marshall specimens, using Los Angeles abrasion machine, suggested to indicate the ravelling resistance of the asphalt course (Watson et al., 2003).

4.0 Experimental Results and Discussion

4.1 Effect of Fibres

The addition of fibres to the mix design increased stability for both 320 and 170 mixes; however reduced stability of PMB mixes. As predicted the inclusion of fibres significantly reduced binder drain down for all mix designs; however fibre addition showed no consistent effect on air voids, resilient modulus or particle loss.

4.2 Effect of 170 Class Bitumen

The replacement of class 320 bitumen with 170 bitumen caused an increase in stability. This substitution however, caused a reduction in air voids, resilient modulus, binder drain down and both conditioned and unconditioned particle loss.

4.3 Effect of Polymer Modified Bitumen

The stability of the current mix increased with the inclusion of A30P and A20E, as PMBs increase asphalt stiffness. There was however no significant change in stability due to crumb rubber bitumen. The substitution of 320 bitumen for A20E and A30P caused a slight reduction in air voids, though no change for rubber bitumen. Resilient modulus slightly reduced from 320 to A30P, due to plastic behaviour, and rubber and showed a great reduction from 320 to A20E, attributable its elastic properties. The inclusion of A30P and A20E PMBs to the OGA mix reduced particle losses, due to increased consistency, stiffness and toughness. Conversely particle losses were significantly increased from the current mix due to the inclusion of rubber. No change in binder drain down was noted from 320 to A30P, though A20E and rubber significantly reduced binder drain down.

4.4 Effect of Bitumen Content

Air voids in the mixes were seen to reduce with increasing binder content for 320 and 170 mixes, consistent with notion that binder drains down and fills air voids. Though there was little to no change for A20E, which may be due to the use of a stiffer binder that doesn't drain and fill voids. Particle loss of the Marshall specimens reduced with increasing bitumen content for 320 and 170, due to the more sufficient binder film thickness provided. However there was no change for PMBs, perhaps as their increased viscosity allowed sufficient film thickness. The results did not demonstrate a correlation between increased binder content and stability, resilient modulus or binder drain down.

4.5 Effect of Alternate Gradation

A reduction in stability was demonstrated from the current mix and comparable mix (320 @ 4.8% + fibres) to single sized mixes, 70/30 and 80/20. The lower stability in these mixes indicates that stone-on-stone contact was not achieved reducing stability, due to lack of fines. Stability increased for 14mm mix due to its aggregate gradation. As predicted there was an increase in air voids from the current and comparable mix to 70/30 and 80/20, due to less percentage of fines. In line with reduced stability for the single sized mixes, due to insufficient stone-on-stone contact, there was similarly a reduction in resilient modulus. The 14mm mix however showed an increase in resilient modulus. A significant increase in particle loss was found for the single sized mixes, consistent with theory due to less stones to complete the stone matrix and to ensure stone-on-stone contact. A reduction in binder drain down was found for all mixes, attributed to the inclusion of fibres, to prevent binder drain down through the more open structure.

4.6 Discussion

A correlation was found between particle loss and air voids, implying as air voids increased particle loss similarly increase. This increase may be attributed to the fact that as air voids increased aggregate particles no longer maintain stone-on-stone contact, causing poor cohesive bonds between particles increasing susceptibility to abrasive losses. Overall unconditioned particle losses were less than conditioned particle losses, as conditioned samples are suggested to represent aged asphalt. Results showed particle loss to be independent of binder drain down. It was suggested by ARRB, Austroads & AAPA (2000) that binder drain down was indicative of ravelling susceptibility; however this was not indicated by test results. Binder drain down was found to be independent of air voids, partially attributable to the inclusion of fibres and PMBs.

The highest stability was demonstrated by 14mm mix and the lowest in single sized mixes, showing stone-on-stone contact was not achieved. Conversely single sized mixes (80/20 and 70/30) showed the highest percentage of air voids, whilst the 14mm mix had the lowest air voids. The highest resilient modulus was shown by the 14mm mix and lowest by A20E @ 4.7%, due to elastic response of this PMB. The greatest particle losses were demonstrated by the single sized mixes, due to lack of stone-on-stone contact. The lowest particle losses were demonstrated by A20E @ 4.5%, A20E @ 4.9% and A20E @ 5.2% + fibres, consistent with international research. The A30P @ 4.5% and current mix had the highest binder drain down with the rubber mix and A20E @ 4.5% having the lowest binder drain down. Interestingly the mixes with least binder drainage did not include fibres, though fibres did reduce binder drain down.

5.0 Conclusion

The results from this study demonstrate A20E @ 5.2% + fibres mix to be the most desirable mix with respect to particle losses. It is recommended field trials of this mix and others with significantly reduced particle losses and binder drain down be conducted so that a comparison between laboratory and field performance may be made.

As this project nears completion the results require further analysis, an analysis of experimental errors and the final thesis document must be completed. It is envisaged that these works will not only lead to improved durability of the current OGA mix design but also the production of a more sustainable solution with road safety benefits.

6.0 References

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