The Importance of Stone Mastic Asphalt in Construction

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ABSTRACT

There are three major types of asphalt surfacings, characterized by a mixtureof bitumen and stone aggregate. These are: Dense Graded asphalt (DGA); Stone Mastic Asphalt (SMA) and Open Graded Asphalt (OGA). Asphalt surfacings differ by the proportion of different size aggregate, the amount of bitumen added and the presence of otheradditives and material. The first aim of this study is to provide an updated systematic review of the evaluation of stone mastic asphalt in construction. The second aim is to develop knowledge readers and researchers for advantages and disadvantages of stone mastic asphalt to help focus future research in this area.

KEYWORDS: Stone Mastic Asphalt; Dense Graded asphalt; Open Graded Asphalt; Pavemet

INTRODUCTION

The mixture without excessive losses through the dust extraction system. Filler systems that add filler directly into the drum rather than aggregate feed are preferred. Pelletised fibres may be added through systems designed for addition of recycled materials, but a more effective means is addition through a special delivery line that is combined with the bitumen delivery, so that the fibre is captured by bitumen at the point of addition to the mixture. Stone mastic asphalt had its origins in Germany in the late 1960's as an asphalt resistant to damage by studded tyres. Stone mastic asphalt is a popular asphalt in Europe for the surfacing of heavily trafficked roads, airfields and harbor areas. It is also called splittmastixasphalt in German speaking countries and elsewhere may be called split mastic asphalt, gritmastic asphalt or stone matrix asphalt. In Australia it is normally called stone mastic asphalt or SMA for short. There are many definitions of SMA. APRG Technical Note 2 (1993) defines SMA as "a gap graded wearing course mix with a high proportion of coarse aggregate content which interlocks to form a stone-on-stone skeleton to resist permanent deformation. The mix is filled with a mastic of bitumen and filler to which fibres are added in order to provide adequate stability of the bitumen and to prevent drainage of the binder during transport and placement." The European definition of SMA (Michaut, 1995) is "a gap-graded asphalt concrete composed of a skeleton of crushed aggregates bound with a mastic mortar." The binder content is generally increased because of segregation problems. "These materials are not pourable. It is common practice to use additives and/or modified binders in the manufacture of these materials especially to allow the binder content to be raised and to reduce segregation between the coarse fraction and the mortar." Australian Standard AS2150 (1995) defines SMA as "a gap graded wearing course mix with a high proportion of coarse aggregate providing a coarse stone matrix filled with a mastic of fine aggregate, filler and binder." The BCA (1998) defines SMA as "a gap graded bituminous mixture containing a high proportion of coarse aggregate and filler, with relatively little sand sized particles. It has low air voids with high levels of macrotexture when laid resulting in waterproofing with good surface drainage." Technically, SMA consists of discrete single sized aggregates glued together to support themselves by a binder rich mastic. The mastic is comprised of bitumen, fines, mineral filler and a stabilising agent. The stabilising agent is required in order to provide adequate stability of the bitumen and to prevent drainage of the bitumen during transport and placement. At the bottom, and in the bulk of the layer, the voids in the aggregate structure are almost entirely filled by the mastic, whilst, at the surface the voids are only partially filled. This results in a rough and open surface texture. This provides good skidding resistance at all speeds and facilitates the drainage of surface water (Nunn, 1994). The structure of SMA is fundamentally different from dense graded asphalt. This is clear if a mix is considered as merely consisting of stones and mastic (bitumen, fines, filler and stabilising agent). The SMA has a stone skeleton which is bound by a rich (overfilled) mastic. In comparison, conventional dense graded asphalt consists of an underfilled (lean) mastic in which, by volume, only few stones are found. Figure 1 provides a comparison of the structures of SMA, dense graded asphalt and open graded asphalt.

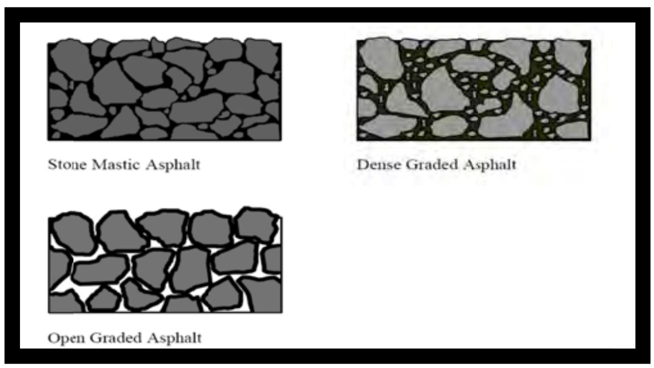

Figure 1: Comparison of Common Asphalt Mix Types

Since its "discovery" in Europe in the early 1960s, and the completion of many trials in America, Australia and several other countries, SMA has risen in status to such a level that it is now regarded as the premium pavement surfacing course for heavy duty pavements, high speed motorways and highways, and other roads having high volumes of truck traffic. (Craig Campbell, 1999)

Stone Mastic Asphalt Properties

The concept behind the development of SMA is fairly straight forward. The SMA mixture consists of two major components:(a) A "skeleton" of large sized aggregate, and (b) A "mortar", or mastic, consisting of the remaining aggregate, the asphalt binder, and a stabilising additive (Haddock, et al, 1993). APRG (1998) indicates that the essence of SMA is a high coarse aggregate content with a high binder and filler content. This binder/filler mixture forms a "mastic". A stabilising agent is normally used to avoid binder drainage during transport and placement. Due to the voids between the coarse aggregate being filled with the rich mastic, the resulting air voids are lower than would otherwise be the case with a conventional dense graded asphalt. Stone mastic asphalt has excellent deformation and durability characteristics, along with good fatigue resistance. Stone mastic asphalt has a rough surface texture which offers good skid resistance and lower noise characteristics than dense graded asphalt. The enhanced deformation resistance, or resistance to rutting, compared to dense graded asphalt is achieved through mechanical interlock from the high coarse aggregate content forming a strong stone skeleton. In dense graded asphalt, the lean mastic provides the stability. The improved durability of SMA comes from its slow rate of deterioration obtained from the low permeability of the binder rich mastic cementing the aggregate together. The increased fatigue resistance is a result of higher bitumen content, a thicker bitumen film and lower air voids content. The higher binder content should also contribute to flexibility and resistance to reflection cracking from underlying cracked pavements. This is supported from the experience from trials undertaken in the United States, where cracking (thermal and reflective) has not been a significant problem. Fat spots appear to be the biggest problem. These are caused by segregation, draindown, high asphalt content or improper amount of stabiliser (Brown, et al, 1997). The rich mastic provides good workability and fret resistance (aggregate retention). The high binder and filler content provides a durable, fatigue resistant, long life asphalt surfacing for heavily trafficked areas. The difficult task in designing an SMA mix is to ensure a strong stone skeleton and that it contains the correct amount of binder. Too much binder assists in pushing the coarse aggregate particles apart, while too little results in a mix that is difficult to compact, contains high air voids and has too thin a binder coating - and hence is less desirable (Wonson, 1998). An SMA, properly designed and produced, has excellent properties: (1) The stone skeleton, with its high internal friction, will give excellent shear resistance, (2) The binder rich, voidless mastic will give it good durability and good resistance to cracking, (3) The very high concentration of large stones - three to four times higher than in a conventional dense graded asphalt - will give it superior resistance to wear, and (4) The surface texture is rougher than that of dense graded asphalt and will assure good skid resistance and proper light reflection. In Germany, surface courses of SMA have proven themselves to be exceptionally resistant to permanent deformation and durable surfaces subject to heavy traffic loads and severe climatic conditions (DAV, 1992). There is little detailed, recorded SMA performance data. It has a very good reputation in Europe and performance has been reported as exceptional in almost every case – perhaps this is a recommendation of its own. Stone mastic asphalt surface courses are reported to show excellent results in terms of being particularly stable and durable in traffic areas with maximum loads and under a variety of weather conditions (Wonson, 1996).

Stone Mastic Asphalt Composition

Stone mastic asphalt is a delicate balance between the mastic and the aggregate fraction requiring good quality aggregates, consistent gradings and careful dosage of mineral fibres to avoid an unstable mix. Variations in production can alter the mix dramatically, hence the use of additives and/or modified binders. The design philosophy revolves around developing a strong stone skeleton with a high stone content, high bitumen and mortar content and a binder carrier. Typical parameters are that the coarse aggregate (> 2.36 mm sieve) makes up 70-80% of the aggregate weight, the fine aggregate 12-17% and the filler fraction is in the range 8-13%. In America’s view of SMA, its percentage of passing sieves, 0.075 mm, 2.36 mm and 4.75 mm are 10%, 20% and 30% respectively and the gap gradation comes into being. Crushed stone over 5 mm occupies 70%, mineral filler and asphalt content are high, and some stabilizers (fibres or polymers) are employed (Shen, et al, undated). Binder contents are typically in the range of 6.5 - 7.5% by mass of mix for 14 mm and 10 mm mixes. Typically, Europeans use slightly lower binder contents. Cellulose fibres (acting as binder carriers) have been found to be excellent stabilising agents, and are typically used at a rate of 0.3% by mass of the mix (Wonson 1996, 1997). The mix is filled with a mastic of bitumen and filler to which fibres are added in order to provide adequate stability of bitumen and to prevent drainage of the binder during transport and placement. The addition of small quantity of cellulose or mineral fibres renders adequate stability of the bitumen by creating a lattice network of fibres in the binder. The addition of fibres also prevents drainage of the bitumen during transport and placement. In summary, the high stone content forms a skeleton type mineral structure which offers high resistance to deformation due to stone to stone contact, which is independent of temperature. The mastic fills the voids, retaining the chips in position and has an additional stabilizing effect as well as providing low air voids and thus highly durable asphalt (AAPA, 1993).

Stone Mastic Asphalt Materials

Selection of materials is important in SMA design. The coarse aggregate should be a durable, fully crushed rock with a cubicle shape (maximum of 20% elongated or flat aggregate). Fine aggregate should be at least 50% crushed. Filler can be ground limestone rock, hydrated lime or PCC. Figure 2 shows the individual components of SMA.

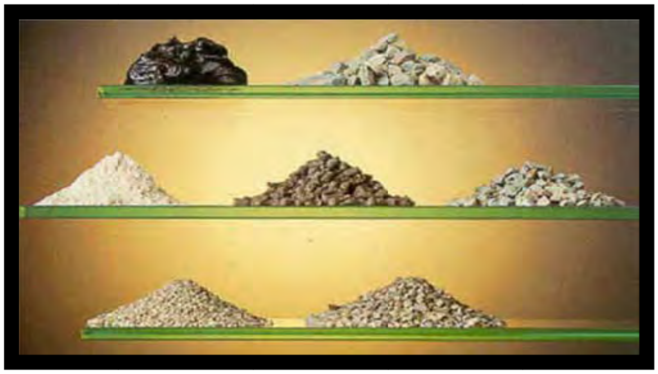

Figure 2: Stone Mastic Asphalt Components

AGGREGATES

The strength, toughness and rut resistance of SMA depends mostly on the aggregate in the mix being 100% crushed aggregate with good shape (cubicle) and stringent limits for abrasion resistance, flakiness index, crushing strength and where appropriate, polishing resistance. Fine aggregate requirements vary from 50% crushed/50% natural sand but trending to 75%/25% to even higher proportions of crushed material. The sand used must be crushed sand as the internal friction of the sand fraction largely contributes to the overall stability of SMA.

Binder

Stone mastic asphalt contains more binder than conventional dense graded mixes, with percentages ranging from about 6.0% up to 7.5%. Heavy duty performance is usually enhanced with polymers and fibers. These help to provide a thick aggregate coating to the aggregate, and the prevention of drain down during transportation and placement. Class 320 bitumen is commonly used for most applications. Multigrade binders and polymer modified binders (PMB) can be used to give even greater deformation resistance. The type of PMB most commonly used with SMA is styrene butadiene styrene (SBS) which is an elastomeric polymer type. Brown et al (1997a) reported that SMA incorporating an SBS PMB produced more rut resistant mixes than SMA with unmodified binder. Superior fatigue lives are also reported as a consequence of using an SMA/SBS system. Modified binders are used for several reasons, including: (1) To increase the resistance to permanent deformation, (2) To increase the life span of the pavement surface, (3) To reduce application and damage risks especially in cases of very thin layers, and (4) To reduce the need for a drainage inhibitor (though this can still be necessary with some PMBs).

Mineral Filler

Mineral filler is that portion passing the 0.075 mm sieve. It will usually consist of finely divided mineral matter such as rock dust, Portland cement, hydrated lime, ground limestone dust, cement plant or fly ash. Experience in Australia has shown that hydrated lime will greatly assist in resisting stripping under adverse moisture conditions and is strongly recommended for inclusion in SMA mixes.

Fibres

The inclusion of cellulose or mineral fibres during the mixing process as a stabilizing agent has several advantages including: (1) Increased binder content, (2) Increased film thickness on the aggregate by 30-40%, (3) Increased mix stability, (4) Some interlocking between the fibres and the aggregates which improves strength, and (5) Reduction in the possibility of drain down during transport and paving. (Craig Campbell, 1999) There are many binder carriers on the market including cellulose, mineral rock, wool fibres, glass fibres, silaceous acid (artificial silica), rubber powder and rubber granules and polymers (less often). When both technical aspects and costs are considered, cellulose fibres have turned out to be the best carriers in practice (Wonson, 1996).

Advantages and Disadvantages of Stone Mastic Asphalt

Stone mastic asphalt has a number of advantages over conventional dense graded asphalt. These include the following: (1) Resistance to permanent deformation or rutting (30-40% less permanent deformation than dense graded asphalt). Van de Ven, et al (undated) also suggests that the stone to stone contact of an aggregate skeleton should prevent the mix from becoming temperature sensitive and thus susceptible to permanent deformation at high temperatures. (2) The mechanical properties of SMA rely on the stone to stone contact so they are less sensitive to binder variations than the conventional mixes (Brown, et al, 1997a). (3) Good durability due to high binder content (slow ageing), resulting in longer service life (up to 20%) over conventional mixes (4) Good flexibility and resistance to fatigue (3-5 times increased fatigue life), (5) Good low temperature performance, (6) Good wear resistance, (7) Good surface texture, (8) Wide range of applications, (9) SMA can be produced and compacted with the same plant and equipment available for dense grade asphalt, and (10) More economical in the long term. (Craig Campbell, 1999)

Perceived disadvantages of SMA include:

(1) Increased cost associated with higher binder and filler contents, and fibre additive, (2) High filler content in SMA may result in reduced productivity. This may be overcome by suitable plant modifications, (3) Possible delays in opening to traffic as SMA mix should be cooled to 40°C to prevent flushing of the binder surface, and (4) Initial skid resistance may be low until the thick binder film is worn off the top of the surface by traffic. (Craig Campbell, 1999). Apart from good stability and durability that ensures a long service life, other advantages are claimed for SMA including: (1) It can be laid over a rutted or uneven surface because it compresses very little during compaction. This also helps to produce good longitudinal and transverse eveness (Nunn, 1994). There is no harm to the final evenness of the surface even when applied in different mat thicknesses. (2) If the pavement lacks stiffness, such that a dense graded asphalt with conventional binder may suffer premature fatigue induced cracking, then it may be beneficial to place SMA because of its improved fatigue resistance properties (Austroads, 1998). (3) An anticipated secondary benefit of SMA is the retardation of reflection cracks from the underlying pavement (Austroads, 1998). An indication of the relative performance of SMA in comparison to conventional dense graded asphalt (DGA) has been provided by Nordic asphalt technologists (Carrick et al, 1991) and is summarised in Table 1.

Table 1: Relative Performance of SMA

Property or Feature	Ranking of SMA Compared to DGA
shear resistance	much better
abrasion resistance	much better
durability	much better
load distribution	somewhat less
crack resistance	better/much better
skid resistance	Better
water spray	equal/better
light reflection	Better
noise reduction	equal/better
public recognition	much better

Life Cycle Costing

Costs are always difficult to obtain and compare. Evidence to date in both the United States and Australia shows that the initial costs of SMA are 20-40% higher than conventional dense graded asphalt in place in road applications. To determine whether SMA is more cost effective than a conventional dense graded asphalt surfacing, whole of life or annualised cash flow techniques are used. These techniques take into account the higher initial cost of SMA (20- 40% higher than conventional dense graded asphalt in place in road applications) and the longer life expectancy of SMA. (Craig Campbell, 1999). APRG (1998) found that if a conventional dense graded asphalt was designed to achieve a 20 year design life based on a certain layer thickness required, say 50 mm asphalt overlay to resist deformation and/or fatigue, then it would not be unreasonable to allow an additional five years life if an SMA was substituted. The increased initial costs of SMA compared to conventional dense graded asphalt result from the use of premium quality materials, higher bitumen content, use of fibres, increased quality control requirements and lower production rates due to increased mixing times. However, costs vary considerably with the size of the project, and also on haul distances. Collins (1996) reported that the State of Georgia had produced a set of life cycle costs based on the State's experience and reasonable mix designs. The analysis showed there were savings in the order of 5% using SMA over dense graded asphalt for overlay work. The analysis used the assumptions of rehabilitation intervals of 7-10 years for dense graded mixes and 10-15 years for SMA. The costings were based on an overlay of an existing Portland cement concrete (PCC) pavement, and a 3% differential discount rate over a 30 year analysis period and assumed: (1) The costs of SMA are on average 25% higher than dense graded asphalt, (2) The period between resheeting is on average 10 years for dense graded and 15 years for SMA, (3) Continued inflation rates at 4%, and (4) A 30 year analysis period. However, even considering the potential for increased costs, the Georgia Department of Transport (DOT) have found the use of SMA to be quite cost effective based on improved performance and the potential for increased service life. The Alaska DOT (NAPA, 1998), has found that the approximately 15% increase in SMA cost compared to conventional mixtures is more than offset by a 40% additional life from a reduction in rutting. Justification for the use of SMA is in whole of life or annualized costing. It appears that SMA could be cost effective for major routes with high performance, durability and frictional requirements. Given that a life span increase of five to ten years can be obtained, and the additional advantages are gained, it is clear that the choice of SMA can be a good investment.

CONCLUSIONS

This paper has reviewed on stone mastic asphalt that addressed these major elements through interviews with anumber of respondents and through an investigation of previous researches used SMA. It is concluded that SMA is an appropriate asphalt in construction. The use of SMA does not show any systemic safety issues. There are however institutional issues that influence the effective use.

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