HIGH SPECIFICATION AGGREGATES FOR ROAD SURFACING MATERIALS IN ENGLAND – UPDATING THE TRAVERS MORGAN REPORT

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Abstract

High Specification Aggregates (HSA) used for the construction and maintenance of skid-resistant road surfaces are relatively rare. They are highly specialised aggregates which can be obtained only from a limited number of geological formations, mainly within the western and northern parts of the UK. Such aggregates are of fundamental importance in underpinning both national and local policies on road safety and skid resistance and this, combined with their scarcity, means that they are often transported long distances for use in areas which do not have indigenous sources of suitable material, as is the case in much of southern and eastern England. This paper reports on a major, ALSF-funded research project which has investigated the current state of the HSA market and has examined some of the sustainability implications involved, updating the findings of the original report on this subject by Travers Morgan Limited in 1993.

Thompson, A. 2008. High specification aggregates for road surfacing materials in England – updating the Travers Morgan report. Pp. 91-98 in Walton, G. (Ed.) Proceedings of the 14th Extractive Industry Geology Conference, EIG Conferences, 109p.

Introduction

High Specification Aggregates (HSA) are those which are used, in combination with suitable binders, to construct road surfaces in situations where a high degree of skid resistance is needed to minimise the risk of skidding-related accidents. Such aggregates are characterised, in particular, by a high Polished Stone Value (PSV) but must also have sufficient strength and durability to withstand heavy traffic. This combination of requirements greatly restricts the range of natural crushed rock and secondary aggregate materials that can be used. Such aggregates are of fundamental importance in underpinning both national and local policies on skid resistance. Combined with their scarcity, this means that they are often transported long distances for use in areas which do not have indigenous sources of suitable material, as is the case in much of southern and eastern England. It also means, however, that the sustainability implications of the way these aggregates are transported and used needs to be scrutinised very carefully.

Background

In 1993, Travers Morgan Ltd. (now Capita Symonds) published a report for the former Department of the Environment on the supply of, and demand for, ***High Specification Aggregates for Road Surfacing Materials*** (Thompson *et al.* 1993). That report was the first systematic study of this particular sector of the aggregates market and its findings have since been widely used by mineral operators and mineral planning authorities (MPAs) alike, with a growing recognition of the need for HSA sources to be considered separately from other crushed rock aggregate reserves (e.g. in landbank calculations).

Within a few years of the publication of the Travers Morgan report, however, the advent of new, proprietary 'thin surfacing' techniques totally changed the way that aggregates are used in road construction and maintenance, in terms of both quantity and specification requirements. Whereas hot rolled asphalt (the main surfacing technique being used at the time of the Travers Morgan study) required HSA to be spread onto the road surface as a single layer of 20mm pre-coated chippings, thin surfacings require such aggregate to be present throughout the full depth of the wearing course, which may be anything up to 50mm deep. A much greater quantity of HSA is therefore required (up to 5 times more for a more typical 30mm thickness surfacing, compared with hot rolled asphalt). By the late 1990s, concerns were therefore being expressed that the demand for these aggregates could have increased by anything up to 5 times the 1993 level, simply as a consequence of this change. If true, this would mean that permitted reserves of these materials would be likely to be consumed at much greater rates than in the past, leading to potential shortages in future years, with much wider planning and sustainability implications.

Concerns were also being expressed regarding the increased quantities of crushed rock fines produced by reducing the aggregate down to the smaller sizes required for thin surfacing materials (typically 14, 10 or even 6mm, rather than 20mm). Quite apart from the increased energy requirements involved, this was seen as a problem in terms of increased wastage: a problem compounded by the fact that much smaller quantities of fines were required for use in thin surfacing, compared with hot rolled asphalt; and by the fact that the fines from

gritstone sources (in particular) are largely unsuitable for alternative end uses other than low grade fill and quarry restoration. Even those uses were becoming more restricted by the effects of the aggregates levy, which gives advantage to secondary and recycled materials. The changes in asphalt technology were therefore being seen by many as driving a less efficient use of relatively scarce geological resources and were also leading, in some cases, to operational difficulties due to the accumulation of unwanted fines within HSA quarries.

In response to these various concerns, and with the backing of the extractive industry, mineral planning authorities, highway authorities and others, a successful application was made by Capita Symonds to the Aggregates Levy Sustainability Fund (ALSF) to support a study to update the original Travers Morgan report. The main aims of the new research were to quantify the current demand for HSA in England, and to quantify and assess the relative sustainability of the current supply pattern for meeting that demand (compared with alternative scenarios that might be envisaged). The focus on England (rather than the whole of the UK as had been covered by the Travers Morgan study) was a limitation imposed by the ALSF. Of necessity, however, the study included a thorough review of HSA sources within other parts of the UK and continental Europe which supplied into England.

The additional focus on sustainability – a concept that was only beginning to emerge at the time of the original Travers Morgan study – was also an important aspect of the new research. Over and above the general sustainability issues associated with all quarrying activities, the key factor here was the question of whether or not the long distance transportation of HSA from limited source areas to widespread and often distant areas of demand, could be justified.

Definition Of High Specification Aggregates

For the purposes of the new research, "High Specification Aggregates" were specifically defined as: *"natural and artificial coarse aggregates (≥3mm) that meet the physical test criteria set out in this report (see below) and that are suitable for use in road surfacing (including surface dressing) applications at the more difficult and/or heavily trafficked sites where high levels of skidding resistance and aggregate durability are required."*

In order to be suitable for use in road surfacing applications, High Specification Aggregates are required to be 'clean, hard and durable' materials. Beyond this, they are specifically required to possess a high resistance to polishing; a high (but ideally not too high) resistance to abrasion; a high resistance to fragmentation and a high resistance to weathering. The specific thresholds used to define HSA for the purpose of the new research are set out in the Table 1 which, it is emphasised, does not constitute a formal specification requirement.

Potential Sources of HSA for use in England

The original HSA database compiled by Travers Morgan was updated as part of the new research with substantial new information on aggregate properties, received from both quarry operators and independent sources (mainly local highway authorities). The revised dataset was used to update the analysis of rock types and geological formations most likely to be capable of yielding High Specification Aggregates. Not surprisingly, the new results show only minor differences compared with this aspect of the findings of the earlier study. Some of the main observations are summarised as follows:

Clastic sedimentary rocks, such as sandstone and siltstone are particularly important sources of High Specification Aggregates, because the component grains generally have differing degrees of hardness and individual grains can be 'plucked' out of the aggregate particles as they wear away, thus maintaining a rough, sandpaper-like 'micro-texture' that is of vital importance to the maintenance of skid resistance. Of these, 'Greywackes' and related rock types have the highest overall quality in terms of measured PSV/AAV categories.

Igneous and metamorphic rocks are generally less able to provide a 'renewable' micro-texture because, despite the variations in hardness of their constituent minerals, they have a much stronger, interlocking crystalline structure that makes it more difficult for individual grains to be plucked out as the aggregate is worn down on the road surface. The main exceptions to this are volcanic tuffs, which resemble and behave more like clastic sediments than igneous rocks, and quartz dolerite, in which the hardness of the quartz grains contrasts markedly with that of the other mineral constituents.

Property	Limiting Value
Polished Stone Value (PSV)	≥ 58
Aggregate Abrasion Value (AAV)	≤ 16
Los Angeles Coefficient (LA)	≤ 30
Magnesium Sulphate Value (MS)	≤ 25%

Table 1. *The Definition of 'High Specification Aggregates' as used in the Capita Symonds study (Thompson* et al. *2004).*

For sedimentary rocks, the degree of consolidation is also an important characteristic, and is influenced by the age of the strata and the extent to which they have been folded and compressed. Sediments of Permian and younger age, as well as most Upper Carboniferous formations, tend to posses very limited resistance to impact, crushing, abrasion and weathering, and therefore do not meet HSA requirements. Older sedimentary rocks, particularly those of Precambrian to Silurian age, are almost invariably much stronger and those with sufficiently high resistance to polishing are often good sources of HSA material. Optimum combinations of strength and resistance to polishing are found in a very limited number of formations, foremost among which are the Carboniferous 'Pennant' Sandstones of South Wales.

As well as meeting specified criteria in terms of aggregate properties, potential HSA resources also need to possess other geological characteristics that make them suitable for commercial exploitation and capable of being processed into aggregates of suitable shape for use in road surfacing. The most important of these criteria are consistency and bedding characteristics. Many sedimentary and volcanic rocks are hampered by their variability and, in particular, by their intimate association with interbedded rock types of markedly inferior quality, such as shales.

As a consequence, despite the remarkable diversity of rock types found within the UK, relatively few formations possess all of the characteristics needed to meet HSA requirements. Despite these limitations, there is no real shortage of potential resources, but very few of these occur in locations where their extraction would be both economically justified and environmentally acceptable. In the wider interests of sustainability (i.e. to meet the needs of future generations as well as those of the present), these limitations on the availability of exploitable resources need to be taken into account in planning for the future supply of these important minerals.

Road Surfacing Materials

In order to understand the changing influence of asphalt technology on HSA demand, it is important to know something about the various different types of road surfacing materials in which HSA are used. Figure 1 illustrates how these 'surfacing' materials relate to the overall structure of a modern flexible (i.e. bituminous-bound) road pavement. The various surfacing options currently fall into six generic groups:

- ***Hot Rolled Asphalt (HRA)*** – characterised by a mix of coarse and fine aggregate bound by a

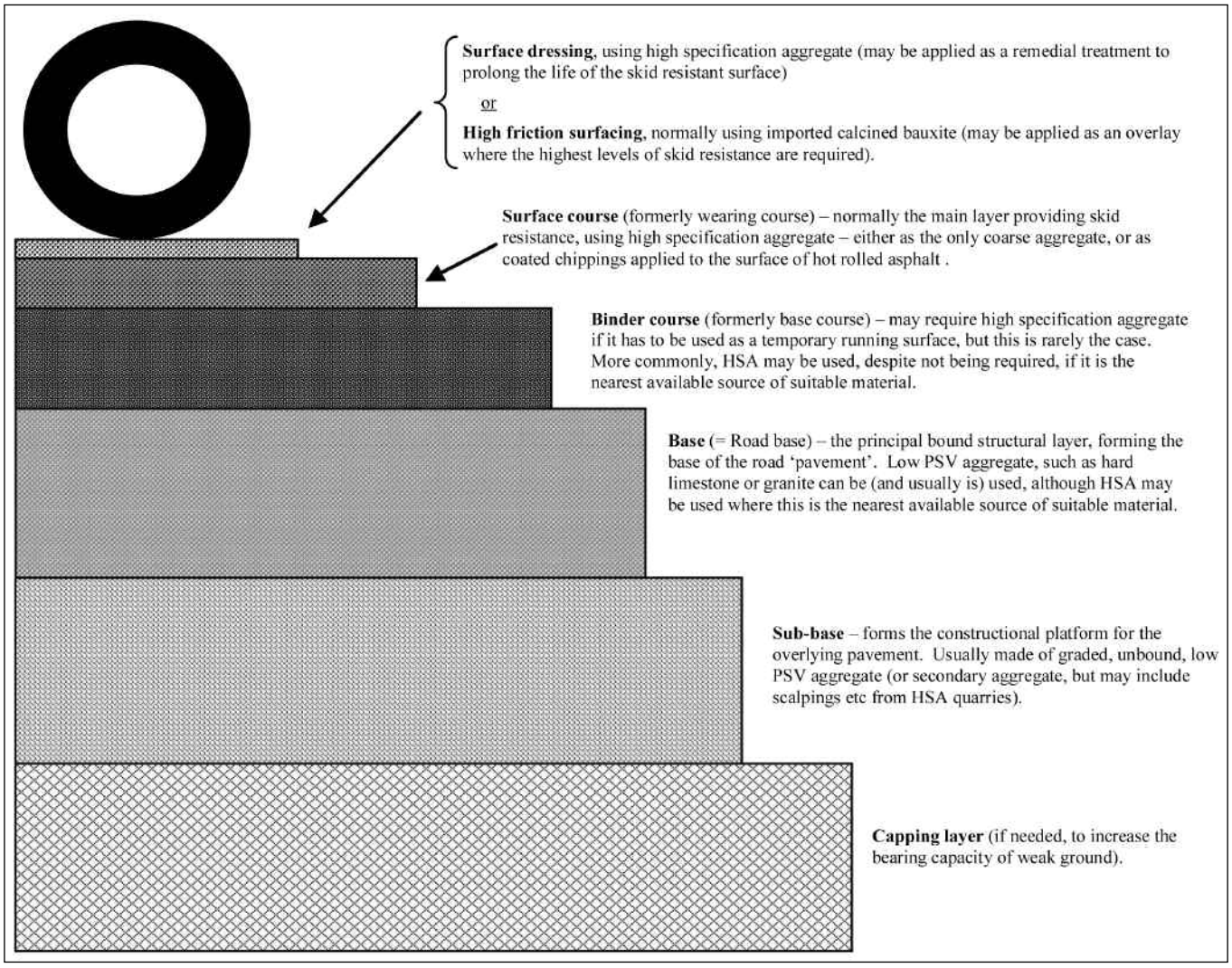

Figure 1. *The Main Structural Elements of a Modern, Flexible Pavement (SOURCE: Thompson* et al. *2004).*

bituminous binder with mineral 'filler' added to provide additional stiffness. Pre-coated, single sized HSA 'chippings' are rolled into the surface immediately after laying to provide the necessary skid resistance. This offers advantages, compared with alternative systems, in terms of overall reduced HSA requirements but is relatively noisy compared with most other surfacings. Concerns about noise as well as construction delays and associated costs mean that HRA is no longer used on the trunk road and motorway network, but on many local authority roads, especially where noise is not an issue, HRA may provide the optimum solution.

- Coated Macadam ('Asphalt Concrete') Mixtures – characterised by an interlocking 'skeleton' of coarse aggregate, usually bound by a bitumen or modified bitumen binder, with relatively little fine aggregate. They provide limited texture depth compared with other options, but High Stone Content Macadams are better in this respect and are often used as surface courses, primarily on low speed and/or lightly trafficked roads.

- Stone Mastic Asphalt (SMA) Mixtures – these also comprise an interlocking coarse aggregate skeleton but with a 'mastic' mortar comprising bitumen and filler with little or no fine aggregate. They provide a negatively textured surface which combines noise reduction with good texture depth and skidding resistance.

- Thin Surfacing Systems – these modern, negatively textured surfaces generally use smaller sized coarse aggregate and enhanced performance binders which allow them to be laid at reduced thicknesses. They primarily include Thin Asphalt Concrete and Thin Stone Mastic Asphalt systems (i.e. thin variants of the two mixtures described immediately above). Some concerns regarding their durability compared with HRA surfacings have been expressed by Local Highway Authorities but this is likely to improve as technology advances and as experience in the use of these materials grows. Providing they are properly installed, however, these systems will always have advantages in terms of reducing noise and traffic delays, and are likely to remain the preferred solution for the most heavily trafficked roads, particularly trunk roads and motorways.

- Surface dressing systems are intended primarily as a maintenance treatment to prolong the life of a structurally sound pavement that has fallen below the 'investigatory level' of skid resistance. Surface dressing unavoidably produces a relatively noisy running surface, compared with thin surfacing, although the latest technological developments offer significant improvements in this area. Moreover, these disadvantages must be balanced against the reduced quantity of HSA required per application. Taking this into account, the best surface dressing systems could actually provide a serious alternative to thin surfacings in terms of overall sustainability.

- High Friction surfacings using imported calcined bauxite are applied as overlays to other types of surfacing and are potentially very effective in reducing the overall requirement for HSA from 'domestic' sources, but their cost is rising rapidly in line with world shipping prices and other, more cost effective solutions may need to be found.

Detailed Specification Requirements

The requirements for aggregates used for different types of surfacing on all trunk roads and motorways within England are based on well-researched specifications and design guides issued by the Highways Agency. Very similar requirements are adopted by most Local Highway Authorities for the rest of the road network, with much greater conformity being evident now than at the time of the original Travers Morgan study in 1992/93. A substantial minority of local authorities do, however, still adopt minor modifications and/or additions, to suit local circumstances. The Highways Agency's guidance deliberately provides for flexibility in this respect, acknowledging that, where aggregate of a 'lower' specification has a proven history of satisfactory performance in a given situation, then the requirements set out in the specification can be relaxed to allow for its inclusion.

Evidence obtained in the new research suggests that, although more than half of the local authorities take advantage of this flexibility, the overall effect has been to increase, rather than relax the overall PSV requirements. Of the other authorities who responded to the Capita Symonds' survey, most felt the situation balanced out, and only two stated that the net effect was to reduce PSV requirements.

This trend, along with the more general increase in conformity compared with the original study almost certainly reflects the growing fear of litigation in situations where accident investigations reveal inadequate skidding resistance. The need to provide a defence against such litigation is highlighted in the IHT Code of Practice for Maintenance Management as part of the reasoning behind skid resistance performance indicators. Over-specification also reflects the fact that most Local Authorities are not yet using Pavement Management Systems properly to assess the performance of different materials. Those authorities are therefore unable to develop the evidence-based policies that HD36/99 seeks to encourage.

Performance Requirements and Monitoring

In the design of road surfacing materials, attention has, understandably, been focused on skid resistance and noise reduction. Durability has clearly also been considered but mainly from the perspective of ensuring that materials are fit for purpose and that they provide acceptable value for money. From a sustainability perspective, much greater consideration now needs to be given to the long-term durability of materials, (including the influence of different aggregate sources and the potential benefits to be gained from in-situ mechanical retexturing of worn-out surfacings). These factors directly influence the frequency of replacement and thus

the frequency with which all of the impacts associated with aggregate extraction, transportation and installation are experienced.

This was an area which the Capita Symonds study had hoped to shed considerable light upon. Regrettably, however, it was found to be an area where very little robust empirical evidence is available, and where substantial additional effort will therefore be needed if sustainability criteria (other than skid resistance and noise reduction) are to be taken properly into account in the future design and procurement of road surfacing materials. To address this point, a key recommendation from the Capita Symonds study (largely echoing one that had been made earlier in the Travers Morgan report) was that detailed record-keeping by local highway authorities and Highways Agency contractors is needed, through the proper use of Pavement Management Systems, so that more sustainable solutions and evidence-based policies can be developed. Specifically, systematic data collection is needed regarding the type of surfacing material and the source of aggregate used in each road surfacing contract, correlated with subsequent performance monitoring of skid resistance for that particular stretch of road together with traffic volumes and the nature and timing of subsequent maintenance treatments and/or replacement.

Performance-based Specifications are increasingly being encouraged, with the aim of allowing still greater flexibility in the choice of materials. In the absence of a clear understanding of the performance achieved by specific aggregates in different situations, however, these are likely only to encourage greater caution, thereby increasing the demand on high PSV sources even further.

Demand for High Specification Aggregates in England

Of the 154 local highway authorities contacted to obtain information on HSA demand, only 53 were able to reply. The pattern of response, compared with that achieved in the original Travers Morgan study, suggests that the creation of unitary authorities and the privatisation of highway functions in other county councils has greatly diminished both the ability and inclination for many of these organisations to respond to questionnaire surveys of this sort. By contrast, there were excellent and very detailed responses from authorities that still have 'traditional' county materials engineers. These, however, were insufficient to provide a reliable estimate of demand for the country as a whole. Demand was therefore assessed from the more comprehensive sales information provided by the HSA producers.

Considerable effort was devoted to the task of identifying all UK sources that currently supply HSA to England, and positively eliminating a large number of potential sources that do not. Detailed sales information was then obtained from almost all of the 59 confirmed suppliers, including (for quarries in Wales, Scotland and Northern Ireland) separate figures for sales to England. Figures were also obtained for two sources in France that supply to England. The locations and names of all but the two French quarries are shown in Figure 2. Further details of each of these sources are provided in Tables 7.1 to 7.4 of Thompson *et al.* (2004).

On the basis of this information, the total 'specified demand' for PSV 58+ HSA within England, in 2002, is calculated to be 6.126 Million tonnes (Mt). This is 2.3 times greater than the corresponding figure of 2.63 Mt for England in 1992 (i.e. an increase of 130%).

The portion of this market supplied from sites within England, in 2002, is calculated to be 3.795 Mt. This compares with a figure of 1.715 Mt supplied from English sites in 1992, and represents an increase of more than 120%. Over the same period, the portion supplied to England from other parts of the UK and northern France has increased by more than 150%, from 0.915 Mt to 2.331 Mt. The dependence on imports has therefore increased at a faster rate than the demands being made on HSA sources within England, and the proportion of English demand supplied from English sources has fallen from more than 65% in 1992 to just under 62% in 2002.

Information on the breakdown of aggregate sales by type of surfacing material demonstrates the remarkable effect of the changes in asphalt technology that have taken place since 1992 (Figures 3 and 4). Whilst the proportion of aggregate used in macadam surfacing (including generic SMAs) has remained similar (around 35 to 37%) in each of the two surveys, the proportion (by weight) of HSA used in Hot Rolled Asphalt has reduced from 28.4% to 2.2%, and the proportion used in surface dressing appears to have fallen from 36.6% to 7.5%. In their place, proprietary thin surfacings of various types now seem to account for a total of 53.4% of all HSA consumption. It should be emphasised that these figures relate to the quantities of HSA involved, not to the surface area treated, and are therefore distorted by the fact that thin surfacings utilise a much greater quantity of HSA per m^2 than either HRA or surface dressing. The reduction in use of HRA and surface dressing, though substantial, has therefore been less dramatic than these figures suggest.

The Supply of High Specification Aggregates to England

An extremely important finding of the Capita Symonds study is that, although the specified demand for HSA had substantially increased since 1992, (as predicted by those who had expressed concerns), the actual rate of supply of these materials (i.e. the total production from HSA quarries, indicating the rate at which reserves are being consumed), had changed very little. The total rate of production (including quarry fines, scalpings and other material not sold to HSA specifications) at English HSA sites in 2002 was 8.416 million tonnes. This was only slightly higher than the equivalent figure of 8.24 million tonnes in 1992. This implies that a much higher proportion of HSA production now goes into materials where such aggregate is required by *specification* and, in this sense, the 'efficiency' of utilisation of HSA resources could be said to have substantially increased. Of course, not all of that aggregate is fully utilised in providing skid resistance, since most of it is not exposed at the surface of the material in which it is laid. In this respect, the situation is actually little different to that in 1992, when HSA was often used in the body of hot rolled asphalt, despite the fact that it was only needed by *specification* in the separate pre-coated chippings applied to the surface.

Figure 2. *The Location of all active HSA Sources in the UK which supplied HSA to England in 2003 (Thompson* et al.*, 2004).*

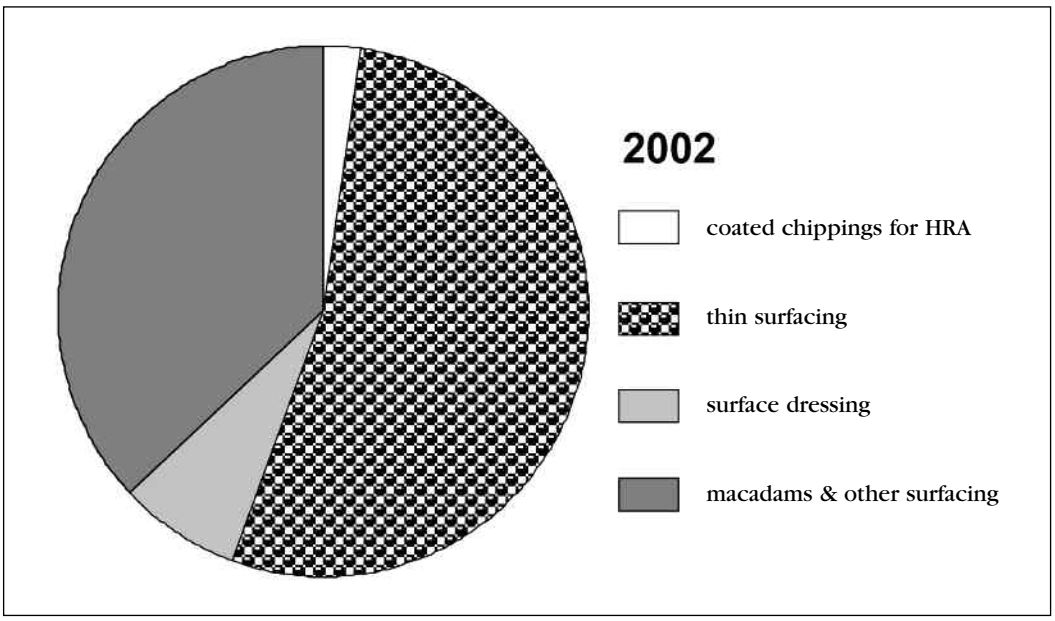

Figure 3. *Breakdown of HSA Output (tonnes) in 2002 by end use, for a sample of 23 HSA sources (Thompson* et al. *2004).*

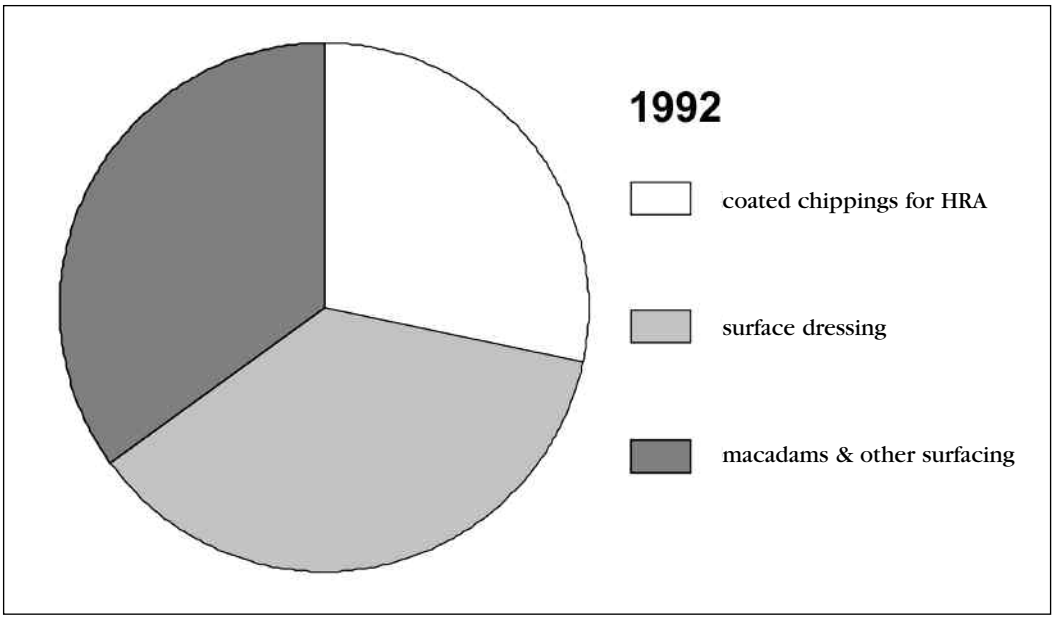

Figure 4. *Breakdown of HSA Output (tonnes) in 1992 by end use, for a sample of 56 HSA sources (Thompson* et al. *2004).*

Another important observation from the new research is that, despite the limited increase in total output, the current (January 2003) 'lifetime' of permitted reserves at all of the HSA sites within England (including a small number of inactive or dormant sites not shown in Figure 2) has been reduced, from 21 years in 1992, to just 17 years, in 2002. This is directly related to the reduced stock of HSA reserves available (146 Mt in 2002, compared with 177 Mt in 1992). If the calculations are limited to reserves at only active HSA sites, the problem is more acute. Current reserves in England are limited to around 128 Mt and the corresponding lifetime is reduced to just 15 years (from 20 years in 1992). Given the uncertainty of being able to rely on dormant and inactive sites for future supplies, this figure is perhaps the most significant, and points to a 'need' for new reserves of HSA being permitted as a high priority, if the future supply of HSA is to be maintained in accordance with anticipated demand.

This 'need' does, of course, have to be considered in the context of the Government's move away from the ethos of *'predict and provide'* to the modern concept of *'plan, monitor and manage'* (i.e. the notion of limiting future aggregate provision to the rates of production that can be sustained by the source areas involved, rather than necessarily always providing for the anticipated level of demand).

It must also be recognised, however, that, because of their relative scarcity and their importance in underpinning the Government's policies on skidding resistance, High Specification Aggregates should be seen as a national, strategic resource. Any parochial restriction on the future availability of such resources could have serious consequences in terms of road safety and skidding-related accidents. In the wider context of sustainability (which, after all, is the driving force behind the policy change), this implication needs to be taken very carefully into account.

To facilitate this, the Capita Symonds' report recommends that Mineral Planning Authorities should differentiate between resources of High Specification Aggregate and those for other, more general applications, with separate landbanks being maintained for each. That recommendation has since been reflected in para. 4.5 of Annex 1 (Aggregates) to the new Minerals Policy Statement 1 (Department for Communities and Local Government, 2006).

Future Trends

Of the various factors likely to influence future trends in HSA demand, most seem to point to an expectation of either minimal change or a slight reduction, with only two groups of factors (traffic forecasts and vehicle design) suggesting a probable increase. There is, however, considerable uncertainty in the scale of effects likely to be associated with many of these factors, and it would therefore be prudent, from a minerals planning perspective, to anticipate a modest increase in demand over the next decade.

Conclusions and Recommendations

The new research by Capita Symonds, as summarised in this paper, has updated the original 1993 Travers Morgan report to give a fully revised assessment of the market for High Specification Aggregates (HSA) for skid resistant road surfacing in England, and has begun to highlight some of the sustainability issues relating to the supply of these important materials.

The research has explained and quantified the effects of the substantial changes in asphalt technology that have occurred since 1993, demonstrating a 2.3 -fold (130%) increase in the 'specified demand' for HSA as a direct consequence of the introduction of thin surfacings. Despite this, the rate at which HSA resources are being consumed has changed very little since 1992, implying that a much higher proportion of HSA production now goes into materials where such aggregate is required by specification than was formerly the case. In this sense, the 'efficiency' of utilisation of HSA resources has substantially increased.

Despite the limited increase in total output from HSA sites, the current lifetime of permitted HSA reserves within England has been reduced from 21 years in 1992, to just 17 years, in 2002, and to only 15 years if reserves at dormant and inactive sites are excluded. This is directly related to the reduced stock of HSA reserves available.

Of the various factors likely to influence future trends in HSA demand, most seem to point to an expectation of either minimal change or a slight reduction. There is, however, considerable uncertainty and it would therefore be prudent, from a mineral planning perspective, to anticipate a modest increase in demand over the next decade. In the interest of reducing some of these uncertainties, future changes in demand within this specialist sector of the aggregates market need to be monitored, as do the various driving forces involved. This will require essential data to be collected by local authorities and Highways Agency maintenance contractors through the use of Pavement Management Systems (PMS), but guidance is urgently needed to ensure that this data is consistently recorded, stored and easily retrieved when required for analysis.

There is also a need for more detailed monitoring of the **supply** of HSA materials, at least until such time as the PMS records are substantially improved. However, although detailed recommendations were provided on this, the prospects of their implementation in the current economic climate seem remote.

Acknowledgements

This paper is based on research carried out by Capita Symonds Limited (formerly Symonds Group Ltd., and before that, Travers Morgan Ltd.), for the Office of the Deputy Prime Minister under research contract SAMP/1/039. The work was funded by the Aggregates Levy Sustainability Fund (ALSF) administered by the Mineral Industry Research Organisation (MIRO), on behalf of the Department of the Environment, food and Rural Affairs (Defra). The research benefited throughout from peer review provided by a project steering group comprising:

Dr. Brian Marker – *Office of the Deputy Prime Minister (ODPM)*

Phil Gordon – *Planning Officers' Society (POS)*

Dave Parrish – *Regional Aggregate Working Parties (RAWPs)*

Graeme Richards & John Lay – *Quarry Products Association (QPA)*

Paul Allison – *British Aggregates Association (BAA)*

Robert Dudgeon – *Highways Agency (HA)*

Len Parker – *Institute of Highways and Transportation (IHT)*

John Wale and Steven Child – *County Surveyors' Society (CSS)*

Derren Cresswell – *Mineral Industry Research Organisation (MIRO)*

The author is also especially grateful to Chris Curtis (Hanson Aggregates), David Williams (Lafarge Aggregates) and Gordon Lemon (RMC Aggregates) for their sustained interest following the publication of the original Travers Morgan Report that prompted the proposal for this research. He is also grateful to all those who contributed to a three month consultation exercise on an early draft of the main report and to the many individual aggregate producers and specifiers who provided detailed information in response to the questionnaire surveys.

References

Department for Communities and Local Government. 2006. Minerals Policy Statement 1: Planning and Minerals. The Stationery Office, London, 35pp, including Annexes.

Thompson, A., Greig, J.R., and Shaw, J. 1993. High Specification Aggregates for Road Surfacing Materials: Technical Report. Report to the Department of the Environment. Travers Morgan Limited, East Grinstead, 270pp.

Thompson, A., Burrows, A, Flavin, D. and Walsh, I. 2004. The Sustainable Use of High Specification Aggregates in England: Report to the Office of the Deputy Prime Minister and the Minerals Industry Research Organisation. Capita Symonds Ltd, East Grinstead, 130pp + Appendices.