LARGE AGGREGATE MIXES IN BASES

Dr S J Emery

Group Technical Director
Colas Southern Africa Pty Ltd
Isando, South Africa

SUMMARY

A major South African research project was directed at cost-effective heavy-duty asphalt pavement layers. The results of this project led to the implementation of Large Aggregate Mixes for Bases (LAMBS), wherein the basecourse of pavements is provided by a bitumen-bound layer. This is topped with a thin conventional asphalt wearing course, giving a total bitumen pavement thickness in the order of 150-170mm.

LAMBS are defined as asphalt mixes which obtain their strength and resistance to deformation from aggregate interlock. This is readily achieved by using large aggregate in the order of 37,5mm and 53 mm. LAMBS do not presuppose a specific grading - rather, the approach optimises the properties of available resources in terms of raw material and plant. The applications for Large Aggregate Mixes for Bases (LAMBS) are presented. The mix design procedure is discussed, including the latest revisions following experiences on various contracts.

1 INTRODUCTION

With the growth in traffic, increasing use of heavy vehicles, and expected increases in axle weights, the need for stronger road pavements is increasing. The Southern African Bitumen and Tar Association (SABITA) in partnership with the road construction industry and the CSIR, launched a research and implementation project directed at the development of cost-effective heavy-duty asphalt layer pavements. The phrase 'cost-effective' was the key to acceptance of these asphalt layers. Previous mix designs for asphalt pavement layers had been uncompetitive due to the cost of the bitumen and crushed stone components.

To give perspective to the applications for these asphalt layers it is necessary to briefly review current practice in terms of surfacings and pavement layers.

<u>Asphalt surfacings</u>
Asphalt surfacings are common for medium and high traffic roads in South Africa. They are generally thin by comparison to American and European standards, because thick asphalt layers have not been cost-competitive here. Accordingly these surfacings add little structural strength, and the underlying basecourse layer carries much of the loading.

<u>Basecourse</u>
The basecourse (or base) tends to be constructed from natural gravels (materials class G4 in road parlance[1]) or crushed stone (materials class G1 or G2). As supplies of natural gravel have been used up, Institute of Quarry members will have noticed the swing towards crushed stone. It is less common to find stabilised base layers due to cost considerations and problems with reflective cracking from cement stabilisation. For the heavy traffic roads, basecourses tend to be crushed stone. The use of conventional BTB asphalt bases is rare, because they are not cost competitive.

The performance of these crushed stone basecourses requires very high levels of compaction density and virtual impermeability. This in turn places tight limits on the grading of the material[2], which has increased the quarrying costs. As the traffic demands grew, so the grading limits have tightened up even further to the point where some of the current specifications must rather frustrate members of the Institute of Quarrying.

Concrete surfaced roads
The combination of thin asphalt surfacings and crushed stone basecourses is not adequate for very high traffic levels, and concrete is used in South Africa for these roads. The construction cost is higher than bituminous surfaced roads, but the life is longer. Sophisticated lifecycle cost analysis[3] is always used with major roads in South Africa, and this shows the long term advantage of concrete roads.

Large Aggregate Mixes for Bases (LAMBS)
The research project on heavy duty asphalt pavements was aimed at addressing the gap between concrete roads and asphalt surfacings/crushed stone base pavements. The results of this project led to Large-Aggregate Mixes for Bases (LAMBS)[4]. LAMBS are defined as asphalt basecourse mixes which obtain their strength and resistance to deformation from aggregate interlock. This is readily achieved by using large top size aggregate in the order of 37,5 mm and 53 mm. LAMBS layer thicknesses are typically 100-140mm thick.

For LAMBS to be economically viable, there are severe cost constraints which have led to three important differences between LAMBS and conventional BTB asphalt bases:

- the bitumen content (b.c.) is reduced; a typical LAMBS b.c. of 4% compares with a typical BTB b.c. of 5,5%,
- the proportion of large sized stone is greater in LAMBS compared to conventional BTB asphalt bases, reducing the crushing and screening required and thus the cost,
- LAMBS design does not presuppose a specific grading - rather, the approach optimises the properties of available resources in terms of raw material and plant. Once again this reduces any cost of re-crushing and/or re-screening to meet a tight specification.

For continued economic viability, these differences must be maintained which means controlling bitumen and stone cost escalation to below that of cement or crushed stone.

2 LAMBS TECHNOLOGY

The LAMBS technology was developed by a detailed laboratory study, followed by various field trials to validate the perceived benefits and the design methodology. The Heavy Vehicle Simulator (HVS) was then used to quantify design criteria for LAMBS and to assess its performance by means of accelerated testing.

Transfer of technology was stressed in order to verify its soundness, to facilitate its acceptance by the industry and to accelerate its implementation. This took the format of technical presentations (South Africa, United States and United Kingdom), demonstrated projects (Cape Town, Dundee and Heidelberg road trials), technology transfer to authorities and consultants (at project level) and seminars in the main centres of South Africa.

The advantages of LAMBS include the improvement in the structural capacity of the pavement at reduced cost resulting from:

- the increase in bearing capacity as aggregate size increases relative to layer thickness,
- the increase in binder film thickness for a given binder content (by mass) as maximum size of aggregate increases, resulting in greater durability,
- the increased resistance to indentation, abrasion and deformation as maximum stone size increases,
- the decrease in material cost because of the savings in binder content on account of the smaller aggregate surface area which needs to be covered as aggregate size increases.

The applications for LAMBS (overlaid with a thin asphalt wearing course) include:

- heavy traffic roads (12-50 million standard axles over the design life or 12-50x10^6 E80s)
- very heavy traffic roads (>50x10^6 E80s)
- aircraft aprons and taxiways
- container terminals and other industrial areas
- rehabilitation projects which require a thick asphalt overlay
- construction projects where time is of the essence, such as busy roads.

3 DESIGN OF LAMBS

3.1 Design procedure

The design of LAMBS is based on a three-level rejection analysis of mixes manufactured with a grading selected based on available aggregate fractions. The trial mixes should contain at least three different binder contents and two filler contents. The proposed tests to be conducted in each of the phases are summarised below. The original design criteria of LAMBS are given in Table 1.

- Phase I : determination of bulk relative density, maximum theoretical bulk density, void content, voids in mineral aggregate and voids filled with binder. Latest practice is to include gyratory compaction testing to investigate the likely effects of compaction

- Phase II : determination of indirect tensile properties, including resilient modulus and indirect tensile strength

- Phase III : determination of resistance to permanent deformation by means of the dynamic creep test

Table 1 Original design criteria of LAMBS

Property	Criterion
Density	Aim for maximum
Void content	Minimum 3%, maximum 6%
Voids in mineral aggregate (VMA)	Dry side of minimum VMA vs binder content, minimum 12%
Voids filled with binder	Minimum 72%, maximum 80%
Resilient modulus @ 25°C/10Hz	Minimum 2000 MPa (stiff layer) 1000-2500 MPa (flexible layer)
Indirect tensile strength (25°C)	Minimum 800 kPa
Dynamic creep modulus (40°C)	Minimum 10 MPa

The pavement structure influences the structural response and performance of LAMBS as the response of underlying layers to loading influences the stresses and strains in the upper asphalt layers. During the design phase it is important to ensure that the structural behaviour of the pavement subjected to loading is incorporated in the mix design of LAMBS.

Pavement design and mix design should, therefore, form an interactive process. If LAMBS are to overlay a flexible structure, the emphasis of the mix design is on the provision of LAMBS of low stiffness, unless the thickness of the LAMBS layer is such that it can protect the underlying layers effectively. In the latter case, LAMBS is designed to have a great stiffness which can be achieved by selecting mixes with relatively high filler contents and low binder contents. If LAMBS are intended for use on a stiff supporting structure, such as on a cement treated layer, a mix of high stiffness is also selected.

3.2 Revisions to include gyratory compaction

Revisions have come from the American SHRP research programme, which is a multi-year multi-project research programme aimed at improving highway technology. Part of this programme included new asphalt mix design methods and tests[5]. The use of the gyratory compactor was introduced to investigate the response of an asphalt mix to construction compaction, compaction under design traffic, and refusal (or ultimate) compaction. The gyratory procedure was adapted by the South Africa Department of Transport[6] to LAMBS design, and has led to some additional design criteria (Table 2).

Table 2 Additional design criteria of LAMBS

Property	Criterion
Gyratory compaction	Depends on traffic:
Initial compaction	typically 10
Design traffic compaction	typically 150
Refusal compaction	typically 250

In practical terms, this has reinforced the ability of LAMBS to optimise the properties of available aggregates. The aggregate mix for an approved LAMBS mix design according to the original criteria (Table 1) is shown in Table 3. This mix was tested using the gyratory compactor, and had to be redesigned; the resultant aggregate mix is shown in Table 4, and the simplification is evident[7].

Table 3 LAMBS aggregate mix using original criteria

DESCRIPTION	PERCENTAGE
37,5mm crushed granite stone	12,5
26,5mm crushed granite stone	10
19,2mm crushed granite stone	7,5
13,2mm crushed granite stone	24
9,5mm granite crusher dust (unwashed)	24
9,5mm granite crusher dust (washed)	22

Table 4 LAMBS aggregate mix using gyratory compaction

DESCRIPTION	PERCENTAGE
37,5mm crushed granite stone	12,5
19,2mm crushed granite stone	17,5
9,5mm crushed granite stone	30
9,5mm granite crusher dust (washed)	40

4 EXPERIENCE WITH LAMBS

4.1 Projects

The initial experience was with 10 trial sections of LAMBS. Much Asphalt in the Western Cape constructed these using various gradings to evaluate some of the concepts being developed in the research. Next, 3 fully-instrumented trial sections were constructed at Dundee in KwaZulu-Natal, and evaluated by means of accelerated testing by the Heavy Vehicle Simulator (HVS). Several small projects followed, but the full technology transfer into normal engineering practice came when LAMBS was used as part of the rehabilitation on the M2 Motorway in Johannesburg. The following LAMBS projects have been or will be undertaken up to the end of 1995:

- MR7, Queensburgh, KwaZulu - Natal (1000 tonnes)
- N3, Athlone, KwaZulu - Natal (4000 tonnes)
- Jan Smuts Airport, Gauteng (5100 tonnes)
- Mitchell's Pass, Western Cape (27000 tonnes)
- M2 Motorway, Gauteng (8900 tonnes)
- Outeniqua Pass, Western Cape (33000 tonnes)
- Durban, KwaZulu-Natal (15000 tonnes)
- N10, Olifantskop, Eastern Cape (35000 tonnes)
- Johannesburg, Gauteng (50000 tonnes)
- N2, Mtunzini, Project 1, KwaZulu - Natal (57600 tonnes)
- N2, Mtunzini, Project 2, KwaZulu - Natal (57600 tonnes)

- N2, Mtunzini, Project 3, KwaZulu - Natal (57600 tonnes)
- N2, Mtunzini, Project 4, KwaZulu - Natal (57600 tonnes)

The value of the projects where LAMBS technology has been or is to be used in the near future has exceeded all expectations and the technology has become an integral part of the roads industry. In some of the projects listed, LAMBS were selected in preference to competing granular or cementitious materials; typical are the M2 Motorway in Johannesburg, and the Mtunzini projects in KwaZulu-Natal.

4.2 Technology impact

Apart from the tangible benefits, the development of LAMBS technology has also resulted in a number of intangible benefits to the road industry. The necessary new approach to mix design as a consequence of using larger aggregate sizes led to the development of a performance-related mix design procedure which also found application in the design of and specifications for conventional asphalt mixes. The Standard Specifications for Road and Bridge Works[2] is being revised by the Committee of Land Transport Officials (COLTO) to include specifications for total air void contents, voids in mineral aggregate (VMA), indirect tensile strengths, dynamic creep moduli and other acceptance criteria applicable to the various types of asphalt wearing courses.

Problems with the construction of LAMBS on certain projects necessitated a review of construction practices and of quality assurance methodologies in contractor organisations. This, in addition to trends elsewhere in the world to move towards total quality management and to the certification and performance guaranteeing of products, resulted in greater emphasis on training, technology acquisition and quality. This in turn will impact on Institute of Quarrying members as sections of the asphalt industry turn to an ISO 9000 approach.

4.3 Guidelines on constructability

Segregation in large stone mixes is a common problem, especially in mixes with discontinuous gradings (semi-gap or semi-open) such as LAMBS. It has been shown in the construction of the trial sections and in several large contracts that problems related to LAMBS constructability can be avoided if appropriate measures are taken. These measures affect the stockpiling, coldfeed, screen house, pugmill, hot silos, truck loading, transport and paving. Of these, the raw material stockpiling is of relevance to the Institute of Quarrying.

Attention has to be given to the raw material stockpiling of the aggregate in terms of material sizes and segregation. Because of the large grading spectrum, there will need to be sufficient stockpiles to cover the large LAMBS materials (up to 53mm), as well as maintaining stockpiles for routine mixes. In terms of segregation, the stockpiles are the first phase in the manufacturing process and, if even limited segregation occurs in the stockpile, the effects of this could be exacerbated during the other phases.

5 CONCLUSIONS

LAMBS has established a niche in the market as an economically viable asphalt basecourse layer for heavy to very heavy traffic pavements. The good experiences to date with it, together with improvements resulting from refinements in the design method, suggest that LAMBS is here to stay. For the quarrying industry, LAMBS has an advantage over conventional asphalt base layers or crushed stone layers; with the emphasis on fitting the design to the available aggregate, not the aggregate to the specification, the gradings are wider and more tolerant. The caveat though is that the LAMBS success is based on cost in a competitive market. Its continuation relies on controlling bitumen and stone escalation to below that of cement or crushed stone.

6 REFERENCES

1 National Institute For Transport And Road Research (NITRR). (1985) Guidelines for road construction materials. TRH14, CSIR, Pretoria.

2 Committee For State Road Authorities. (1987). Standard specifications for road and bridge works. Department of Transport, Pretoria.

3 Jordaan And Joubert. (1990) CB-Roads programme V3.1 for cost-benefit analysis Department of Transport, Pretoria

4 SABITA (1993) LAMBS - The design and use of large aggregate mixes for bases Manual 13, Cape Town.

5 Federal Highway Administration (1994) Background of Superpave Asphalt Mixture Design and Analysis Report FHWA-SA-95-003, NCAT demonstration project 101, Washington.

6 Nothnagel, B (1995) Personal communication Materials Engineer, Department of Transport, Pretoria

7 Rossman, D (1995) Personal communication Regional Materials Engineer, Department of Transport, Durban.