POTENTIAL FOR USE OF SAND IN ROAD CONSTRUCTION IN DAR ES SALAAM AND COAST REGIONS

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Coarse aggregates for use in road construction in Dar es Salaam and Coast regions are becoming increasingly scarce and expensive while sand, which is cheaper, is readily available in the two regions. This research aimed at evaluating the possibility of using quarry sands in the two regions as a major constituent material in bituminous road pavement layers. First, the use of sand in sand-bitumen bases for low and medium trafficked roads was studied. The study then continued with the preliminary evaluation of the possible use of the sands in hot rolled asphalt mixes. Results show that Mbagala sand can be used in sand-bitumen bases for low trafficked roads resulting in more than 66% savings in material costs with the potential for use in more trafficked roads. Kisarawe, Mbagala and Kigamboni sands were all found to be suitable for use in hot rolled asphalt mixes with potential savings in material and construction costs.

Key words:*Sand; sand-bitumen; bituminous mix; stabilisation; hot rolled asphalt*

INTRODUCTION

Sources of coarse aggregates as roadbase material in Dar es Salaam and Coast regions are diminishing and the aggregates are becoming more and more expensive while sand, whose cost is much lower, is readily available in the two regions. If stabilised with suitable amounts of stabilisers like bitumen, sand may function as a suitable and economical roadbase material for roads with up to certain levels of traffic loading thus saving on the cost of aggregates.

Single size and desert sands are not usually suitable for stabilising with either cement or lime but can often be effectively stabilised with bitumen, although this may sometimes involve combining sands from two or more sources to obtain a stable grading (Millard 1993). There are therefore good prospects for the use of quarry sand in sand-bitumen mixes. A good example of the effective use of sand stabilised with bitumen is on the Maiduguri-Bama road in Northern Nigeria (Johnston and Gandy 1964) where the pavement was still in good service condition 20 years after construction (Millard 1993).

Sand-bitumen stabilisation is most useful in areas where the climate is hot and dry for the following three reasons; First, sandy soils frequently predominate in these areas, and they may be the only readily available road making material. Second, water is not needed at any stage during the mixing and laying process. And third, the bearing capacity of soils and subbases in arid regions is often high so that quite thin roadbases are required, offsetting the relatively high cost of the binder (Millard 1993).

Research and experience have established that bitumen stabilised sands are an alternative in light and medium trafficked roads and in areas lacking coarse aggregates. The bitumen can range from fluid cutbacks or emulsion that can be used at ambient temperatures to penetration grade bitumen requiring heating and producing the highest stabilities (TRL 1993).

Sand may also be used in rolled asphalt as an alternative to asphalt concrete surfacing. Rolled asphalt is a gap-graded mix which relies for its properties primarily on the mortar of bitumen, filler and sand. The mixtures usually contain 40-50% per cent of coarse aggregates. Mixes made with natural sand are more tolerant of proportioning errors and are easier to compact, and although the air voids are slightly higher, they are discontinuous and the mixes are impermeable (TRL 1993; Millard 1993). Rolled asphalt can also be used as roadbase material. Laboratory studies and full-scale road experiments have established that rolled asphalt bases are extremely strong, durable and superior to other forms of bases (Croney and Croney 1991).

OBJECTIVES

Detailed evaluation of the sand-bitumen mixes with cost comparisons with currently being used alternatives has been carried out, while only preliminary evaluation of the possible use of the sands in rolled asphalt has been done. Quantification of savings in the case of rolled asphalt would require actual design but positive savings are implied as the use of the sands in rolled asphalt has been shown to be viable and sand, being the major and most important constituent in such mixes, is much cheaper than aggregates.

The aim of this study was therefore to evaluate the suitability of sand from a number of quarries in Dar es Salaam and Coast regions, for use as:

(i) bitumen stabilised roadbase material for light and medium trafficked roads in the two regions

(ii) constituent material for rolled asphalt surfacing and roadbase.

TESTS ON NATURAL SANDS

The evaluation covered material from four major sand sources i.e. Kisarawe, Mbagala, Kigamboni and Mpiji. The following preliminary tests were performed on the natural sands:

Particle Size Distribution

The gradation test is important in order to classify the sand as best results are achieved with well-graded, angular sands with a limited amount of fines. The high surface area of fines will also unnecessarily increase the amount of bitumen needed to coat the material. Sieve analysis was performed on all sands to determine the particle size distribution. The results of sieve analysis for all sand sources are shown in Table 1 and their gradations depicted in Figure 1.

Table 1: Gradation of Sands from the Four Sources

Test Sieve Size (mm)	Percent Passing			
	KISARAWE	MBAGALA	KIGAMBONI	MPIJI
4.75	100	100	100	100
2.36	100	100	99.5	100
1.18	94.2	96.9	96.3	96.4
0.5	60.1	74.3	46.3	71.8
0.3	32	54.4	9.7	24
0.15	11	21.3	0.8	1.1
0.075	5	3.8	0.2	0
C_c	1.12	1.06	0.87	1.11
C_u	3.3	3.4	2.0	1.91
Grading	SP	SP	SP	SP

CBR Test

CBR tests were undertaken on laboratory samples of sands to determine their bearing capacity. Typical CBR values for unbound material specified for bases are between 60 and

100 per cent (Ministry of Works 1999). The aim of the CBR test was then to evaluate the insitu strength of the sands and to confirm the need for stabilisation. The results of the CBR tests are shown in Table 2.

vehicles per day and with mean equivalent standard axles per vehicle of 0.5 or less) and in areas lacking coarse aggregates. Design criteria using Marshall test are given in Table 3.

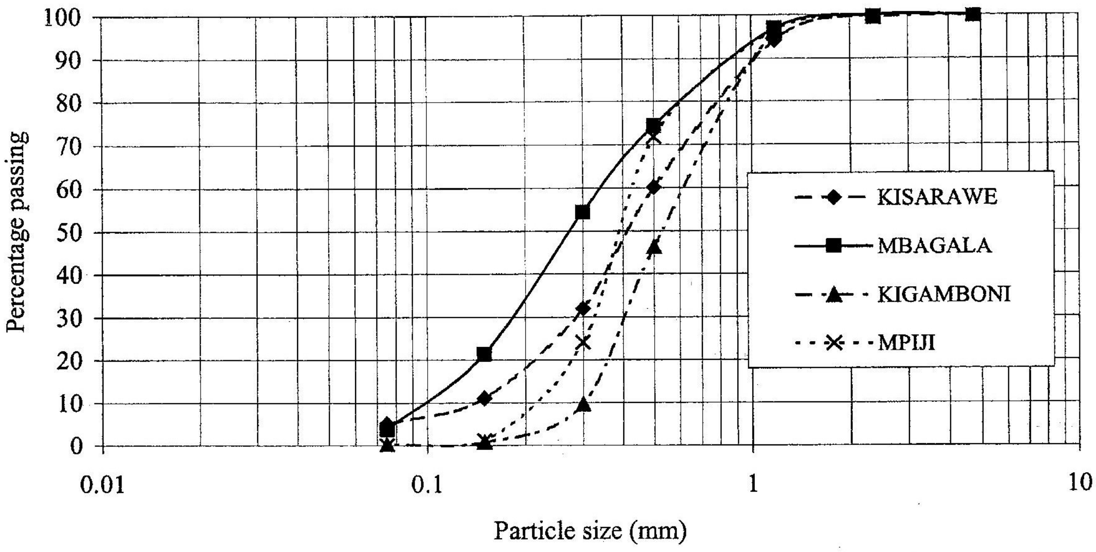

Figure 1 Particle Size Distribution Curves for the Four Sands

Table 2: CBR values for the Four Sands

SAND SOURCE	CBR (%)+
KISARAWE	14.6
MBAGALA	17.7
KIGAMBONI	3.1
MPIJI	2.8

+ at 98% MDD

EVALUATION OF SAND-BITUMEN MIXES FOR USE AS ROADBASE

Criteria for Application

Through research and long-term observation, the Transport Research Laboratory (1993) has established the following conditions for the use of sand-bitumen roadbases applicable to tropical and sub-tropical environments:

(i) Sand-bitumen bases may be used in light and medium trafficked roads (defined as roads carrying less than 300 commercial

(ii) Best results are achieved with well-graded angular sands in which the per cent passing the 0.075 mm sieve does not exceed ten and is non-plastic. High surface area will unnecessarily increase the amount of bitumen needed to coat sand.

(iii) Best results are obtained using penetration grade bitumen of medium hardness such as 100 pen grade.

Table 3: Criteria for Sand-Bitumen Roadbase Materials

	Traffic Classes	
	T1 (<0.3 mil. esa)	T2 (0.3-0.7 mil. esa)
Min. Marshall stability at 60°C	1 kN	1.5 kN
Max. Marshall flow value at 60°C	2.5 mm	2 mm

Source: Overseas Road Note 31 (TRL 1993).

Liquid Bitumen Mixes

Since local sands are likely to be dry, or at worst, only slightly damp and their natural temperature may be as high as 40°C, the cost and energy can be saved by using them without further heating. This calls for the use of liquid asphalt i.e. cutbacks. Sand soils from all four sources were mixed with 3-6% cutbacks of MC30, MC70, and MC800 and the mixed materials were left in a fluffed-up condition for the fluxes in the bitumen to evaporate before they were compacted. In all cases, the specimens crumbled when they were kept in a water bath at 60°C for 40 minutes prior to the Marshall test. Since even the sample with the most viscous liquid bitumen i.e. MC800 failed, it can be concluded that the failure is attributed to the quarry sands not being angular and well-graded enough thus failing to develop the bonding required.

Penetration Grade Bitumen Mixes

The next evaluation carried out was for the use of Penetration Grade Bitumen as usually the more viscous the bitumen the higher would be the strength of the stabilised mix. Although this will necessitate heating the sand as well as the bitumen, the extra energy involved in this heating is comparable with the energy lost in the evaporation of the fluxes in the cutbacks (Millard 1993). The Penetration Bitumen used was 80/100.

Marshall Tests and Results

Marshall test was carried out on samples from the four sources. The total weight of mix for each specimen was 1200 g and bitumen content was varied by 0.5% from 3 to 5.5%. Table 4 shows laboratory results for the four sands and Fig. 2 shows the Marshall properties against asphalt content for the Mbagala sand which

Table 4: Marshall Test Results for the Pengrade Bitumen Mixes from the Four Sources of Sand

SAND SOURCE	ASPHALT CONTENT (%)	STABILITY (kN)	FLOW (mm)	UNIT WEIGHT (g/cm^3)	MAX. SPECIFIC GRAVITY (g/cm^3)	% AIR VOIDS
KISARAWE	3.0	0.55	0.92	1.934	2.401	19.4
	3.5	0.70	1.24	1.964	2.392	17.9
	4.0	0.80	1.57	2.020	2.424	16.7
	4.5	0.84	1.74	2.076	2.474	16.1
	5.0	0.69	2.24	2.076	2.461	15.6
	5.5	0.56	2.89	2.026	2.394	15.4
MBAGALA	3.0	0.65	0.90	1.937	2.404	19.4
	3.5	0.97	1.21	1.968	2.398	17.9
	4.0	1.15	1.41	2.012	2.415	16.7
	4.5	1.40	1.62	2.076	2.474	16.1
	5.0	0.94	1.98	2.056	2.440	15.7
	5.5	0.82	2.27	2.028	2.406	15.7
KIGAMBONI	3.0	0.54	1.12	1.817	2.265	19.8
	3.5	0.66	1.57	1.820	2.226	18.2
	4.0	0.68	1.91	1.870	2.254	17.0
	4.5	0.55	2.16	1.894	2.266	16.6
	5.0	0.48	2.83	1.840	2.190	15.6
MPIJI	3.0			1.738	2.355	26.2
	3.5			1.750	2.261	22.6
	4.0			1.787	2.228	19.8
	4.5			1.760	2.157	18.4
	5.0			1.868	2.262	17.4

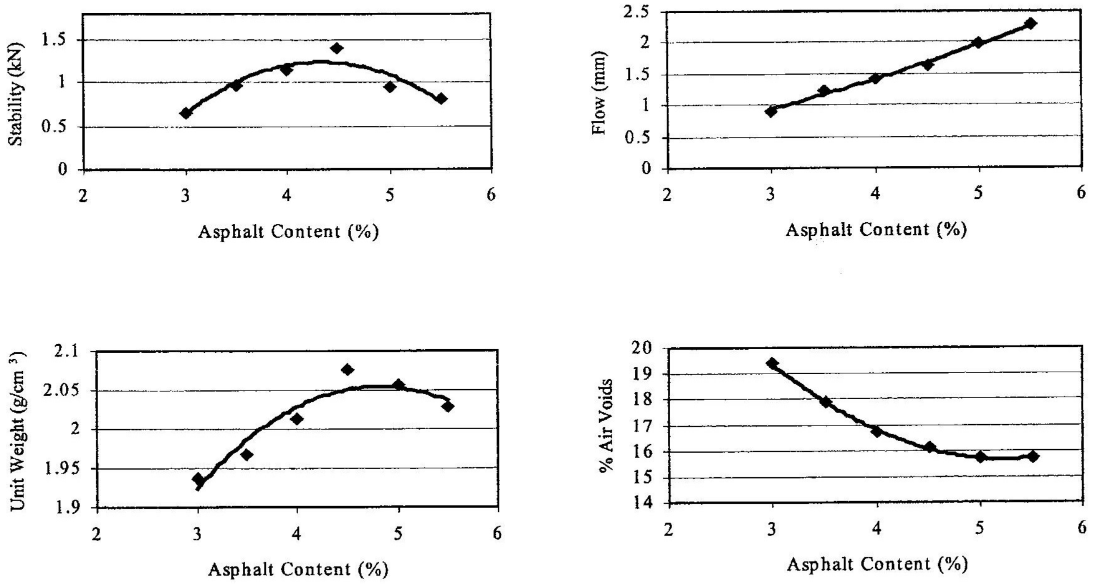

Figure 2 Relationship between Marshall Properties and Asphalt Content for Mbagala Sand Mix

met the design criteria. Overall results are summarised in Table 5. The optimum asphalt content is derived from the maximum stability, as required by the design criteria, and all other values are obtained for the optimum asphalt content.

Only two measurements (unit weight and per cent air voids) were taken for the Mpiji sand as the specimens crumbled in the water bath at 60°C. This is due to the very poor gradation of the sand as can be seen in Fig. 1 and the lowest coefficient of uniformity C_u of 1.91. The surface texture of Mpiji sand is also smooth and round.

Discussion of Tests Results

From Table 5, it can be seen that in the case of Kisarawe sand-bitumen mixes, the maximum stability was below the Marshall test criteria for either of the two traffic levels as specified in Table 3. The flow was however within the range for both traffic levels. The stability of 0.82 kN is not that low and gives hope of the possible use of the sand with some improvements such as blending. The grading as shown in Fig. 1 and the natural CBR of 15 are also encouraging.

In the case of Mbagala mixes, the maximum stability complied with traffic level T1 while

Table 5: Summary of Marshall Test Results for Pengrade Bitumen Mixes

MARSHALL TEST RESULTS	KISARAWE SAND MIX	MBAGALA SAND MIX	KIGAMBONI SAND MIX
Optimum Asphalt Content (%)$^+$	4.2	4.3	3.8
Marshall Stability (KN)	0.82	1.24	0.66
Flow (mm)	1.6	1.58	1.52
Unit Weight (g/cm^3)	2.045	2.044	1.860

+ ORN 31 gives a bitumen content range of 3-6%

the flow complied with both traffic levels criteria. This is due to the better gradation of the sand and its high natural CBR resulting in higher compactness and stabilities.

Kigamboni sand-bitumen mixes failed to meet the Marshall test criteria for either traffic level. This is due to the poor gradation as depicted in Fig. 1, the low coefficient of uniformity value of 2, and the low natural CBR of the sand of 3.1.

The failure of Mpiji samples can be attributed to poor gradation (Fig. 1) also shown by the highest percent of air voids of the compacted mixture (Table 4). The specimens absorbed a lot of water into the voids, thus softening when heat in the water bath resulting in failure. Also, the specimens had the lowest bulk specific gravities and the natural CBR of the sand was the lowest at 2.8.

Cost Comparison

Viability of sand-bitumen bases will not be complete without a cost comparison with the relevant alternative i.e. granular base. Since there are not yet formalised thickness design specifications for sand-bitumen material, the 125 mm thickness that was observed to have performed well in Nigeria (Johnston and Gandy 1964) is used. The 125 mm is considered adequate since the comparison is based on the minimum pavement required for the lowest traffic loading level (less than 0.3 mil. esa) and the material specifications for the sand-bitumen used are the same. The material costs are compared with those of the granular base for the most competitive case i.e. 150 mm of crushed aggregate lying over a strong subgrade for traffic loading less than 0.3 mil. cum. esa. Both are to be surface dressed, and the comparison is therefore on base layers only. Each pavement is assumed to be 6 m wide and 1 km long. The material costs (excl. VAT) are based on Konoike Construction Co. Ltd. rates at the time.

Crushed aggregates (Lugoba) base:

Required volume of material	=	6 m × 0.15 m × 1000 m	=	900 m^3
Total material cost	=	900 m^3 × TShs. 36,000/= per m^3	=	32.4 mil. TShs.

Sand-bitumen base (Mbagala sand):

Required volume of material	=	6 m × 0.125 m × 1000 m	=	750 m^3
Total weight of material	=	2044 kg/m^3 × 750 m^3	=	1.533 × 10^6 kg (1533 tonnes)
Weight of binder	=	4.3/100 × 1533 tonnes	=	65.9 tonnes
Cost of binder	=	65.9 tonnes × TShs. 90,000/= per tonne	=	5.93 mil. TShs.
Weight of sand in mix	=	95.7/100 × 1.533 × 10^6 kg	=	1.4671 × 10^6 kg
Volume of sand	=	Weight of sand in mix/Unit weight of sand		
	=	1.4671 × 10^6 kg/ 1956 kg/m^3	=	750 m^3
Cost of sand	=	750 m^3 × TShs. 6,900/= per m^3	=	5.18 mil. TShs.
Total sand-bitumen cost	=	11.11 mil. TShs.		

This results in minimum savings on materials of TShs. 21.3 mil. per km (66%). This is minimum since in actual practice more aggregates will be required than used in the calculation due to reduced volumes after compaction. If for example the volume of compacted material is typically 80% that of loose aggregates, savings per km would be TShs. 29.4 mil. per km (73%).

PRELIMINARY EVALUATION OF THE POTENTIAL FOR USING THE SANDS IN ROLLED ASPHALT

Sand is the most important constituent determining the strength of hot rolled asphalt mixes. Hot rolled asphalt is a gap-graded mix consisting of bitumen plus three separate distinct sizes of aggregate, namely stone (coarse aggregate), sand and filler. The stone in the wearing course is generally 10 to 15 mm, the sand a natural sand, and the filler limestone. Since rolled asphalt receives its strength from the mortar (sand+filler+bitumen), relatively hard bitumen (usually 40-60 penetration) may be used. The merits of hot rolled asphalt include durability and tolerance to the inevitable manufacturing variations compared with asphalt concrete.

However, use of hot rolled asphalt has remained a challenge in tropical countries where the mortar often softens resulting in excessive deformations. Brien (1978) has developed a design procedure that covers most of the factors that contribute to the performance of an asphalt mix; and in particular the deformation of mixes in hot climates. The procedure uses Marshall test results expressed as 'Marshall Quotient' (Q_m), i.e. Marshall Stability (S_m) divided by Flow (F_m), for comparing the resistance to deformation of mixes. Research has established that in the hottest of temperatures, Marshall Quotient of about 2.5 $kNmm^{-1}$ is required for the most severe sites (e.g. up-hill slow lanes) falling to 1.0 $kNmm^{-1}$ for less severe sites (Brien 1978).

The procedure is carried out by first establishing the Marshall Quotient of the mortar only (containing 13% by weight filler), which is expected to range between 0.7 and 1.2 $kNmm^{-1}$ for potential single-sized sands. The Marshall Quotient of the whole hot rolled asphalt mix is estimated to be 2.4 and 3.0 times the mortar Marshall Quotient after adding 40% and 55% stone respectively (Brien 1978). Table 6 summarises the Marshall test results obtained.

Table 6 shows that all the three types of sand from Kisarawe, Mbagala and Kigamboni can be used in hot rolled asphalt. The Marshall Quotient values are likely to be more than twice those obtained since Brien (1978) has shown that the Marshall Quotient can be increased from 2 to 4 (doubled) by increasing filler content from 7.5 to 20%, and further increased by using harder bitumen. Results in Table 6 used natural sand (without additional fines) and relatively softer bitumen of 80/100 pen (compared to the minimum recommended 60/70 for rolled asphalt).

The potential for using Dar es Salaam and Coast regions' sands in hot rolled asphalt is therefore very high with potential savings in material costs (sand being cheaper than aggregates) and construction costs related to less quality control sensitivity of hot rolled asphalt. The savings will be higher when used as base material due to the more relaxed specifications compared to surfacing.

Table 6: Marshall Quotient Values for the Various Sand Mortars

SAND SOURCE / PARAMETERS	KISARAWE SAND MIX	MBAGALA SAND MIX	KIGAMBONI SAND MIX
Marshall Stability (kN)	0.82	1.24	0.66
Marshall Flow (mm)	1.6	1.58	1.52
Marshall Quotient of mortar ($kNmm^{-1}$)	0.51	0.785	0.43
Projected Marshall Quotient after adding 40% stone ($kNmm^{-1}$)	1.23	1.88	1.04
Projected Marshall Quotient after adding 55% stone ($kNmm^{-1}$)	1.53	2.36	1.98

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

(i) In order to obtain good sand-bitumen stabilised mixes, the sand has to be well-graded (at least to some extent) and angular. This was clearly shown by most samples lacking this quality (e.g. Mpiji and Kigamboni) failing to meet the performance criteria.

(ii) Mbagala sand can be used to construct sand-bitumen bases for light and medium trafficked roads with cumulative traffic load less than 0.3 mil. esa using 80/100 penetration grade bitumen and an asphalt content of 4.3%. This has been shown to be an economical option resulting in more than 66% savings in material costs compared with conventional alternatives.

(iii) Preliminary evaluation indicate that there is potential for using Kisarawe, Mbagala and Kigamboni sands in deformation resistant hot rolled asphalt mixes with possible savings in material and construction costs.

Recommendations

(i) With the increasing scarcity of aggregates in Dar es Salaam and Coast regions, Mbagala sand should be used for the construction of sand-bitumen bases for roads with light to medium traffic. There is demand for many such roads in the two regions.

(ii) Further research is recommended to evaluate the apparent possibility of using Mbagala sand in roads with even higher traffic (up to 0.7 mil. esa) by either using a harder pen grade bitumen or blending with other sands to improve gradation.

(iii) Since gradation can always be improved through blending, the possibility of blending other soils with sands for use in sand-bitumen bases should be looked at. This will enable the other sources of sands, e.g. from Kisarawe and Kigamboni, to be used which might still be more cost effective if reasonable distances are maintained. Blending with other soils may also result in the possible use of liquid bitumen thus saving on energy required for heating.

(iv) This study has been conducted on quarry sand sources since a lot of these are found in the two regions and Dar es Salaam region in particular is well-built reducing the possibility of using the sands along the routes. However, it is highly recommended that field surveys include exploration to establish the presence of deposits of sands of suitable gradation along the road route. This is likely to be more economical and may expose sources of clean sand with the required properties.

(v) With potential savings in construction and material costs, hot rolled asphalt should be considered in most road construction projects in Dar es Salaam and Coast regions. The technical advantages of using rolled asphalt, as established in many studies, have been discussed. The preliminary technical viability of using sand from three sources i.e. Kisarawe, Mbagala, and Kigamboni in such mixes has also been established. Further studies are however required to establish exact mixes and the level of savings compared with conventional alternatives.

NOTATIONS AND SYMBOLS

CBR	=	California Bearing Ratio
esa	=	equivalent standard axle(s)
F_m	=	Marshall Flow
ORN	=	Overseas Road Note
Q_m	=	Marshall Quotient
S_m	=	Marshall Stability
TRL	=	Transport Research Laboratory
VAT	=	Value Added Tax

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