# THE USE OF CORAL ROCK AGGREGATES IN ROAD BASES, A LABORATORY INVESTIGATION USING FOAM BITUMEN

**by**

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***ABSTRACT***

*Road transportation industry has been growing rapidly in Africa. Despite of slow economic growth in most of our countries, population growth is high. Shipment of agricultural produce, commercial as well as imported goods and not neglecting inconsistent income reflux these effect high frequency on the movement of people and goods thus a need in construction, rehabilitation or maintenance of roads inter-regionally as well as rural areas. Sources for superior materials for road construction in Tanzania are exhausting which lead to scarcity of appropriate materials. The haulage cost of good construction materials is high and improvement on road construction materials of low quality in the vicinity of the site becomes an economic option. The practical fact is assessed on the type of methods used and cost effectiveness. Soil improvement for road construction is an appropriate option in developing countries and this comes as a solution to combat day-to-day construction costs. Investigations and researches have to be done to achieve standardised and acceptable soil improvement criteria and yet fulfil the better quality for our road networks.*

*This paper summarises the preliminary and supplementary laboratory investigation carried out on the utilisation of coral rock aggregates in foam bitumen Stabilisation in Tanzania. The use of coral stones in the base or surfacing could possibly imply a substantial save in transport costs of aggregates, as normally accepted materials are not available within the vicinity of coastal regions. The study was done by sampling and laboratory analysis on materials from four quarries. These are along the coast (Dar Es Salaam – Bagamoyo road). The investigation was facilitated by the Institution Co-operation agreement between the Ministry of Works (MoW)/Central Materials Laboratory (CML) and the Norwegian Public Roads Administration (NPRA)/Norwegian Roads Research Laboratory (NRRL) to identify the suitability of bitumen stabilised coral rock aggregates using cold foaming technique. Laboratory tests performed clearly showed that bitumen stabilisation is possible using coral stone aggregate mixed with some river sand.*

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# 1. BACKGROUND

This paper describes the pre-investigation and laboratory testing of the possible use of coral/limestone, natural or stabilised on Dar es salaam – Bagamoyo road. The possible use of relatively weak lime stone aggregate would also imply a significant construction cost savings on future road construction along the coastline where good construction materials are either scarce or none existent.

At that time the ongoing construction and the further planned continuation to Bagamoyo road traverses an area where only coral stone are available within reasonable haul distance. The paper describes the possible use of coral stone aggregates in a bitumen stabilised base layer based on laboratory test results.

The study was carried out under the Institutional Co-operation between MoW/ CML and the NPRA/NRRL. A team consisting of three members from the following institutions, MoW/CML, Dar es Salaam, NPRA/Norwegian Road Research Laboratory and Nodest Vei, Norway carried out the fieldwork during the period 23 – 30 of August 1994. The Laboratory works were carried out both at the CML, Dar es Salaam and at Nodest vei, Norway during the months of September and October 1994.

# 2. EXISTING ROAD AND ENVIRONMENTAL CONDITIONS

## 2.1 Condition of Existing Road

The 43.3 km long project road was in a very poor condition. The first 30 kilometres was badly deteriorated-6 – 7metres wide gravel surfacing consisted of coral stone aggregate. The remaining 13.3 kilometres was a sand/earth road (spots that had caused drainage problems was to some extent filled with coral stone) varying in widths between 5 – 6 metres. Both the vertical and horizontal alignment needed to be improved.

## 2.2 Topography and Climate

The area traversed by the project road follows the low-lying narrow coastal belt between Kunduchi and Bagamoyo at an altitude of about 30 – 100 metres above sea level. The existing road followed a gently undulating terrain for the first 13 km, and to become more rolling for the remaining 17 km. The climate is hot and humid, with an average temperature ranging between 20$^{o}$C to 30$^{o}$C, the hottest months being December and January.

## 2.3 Geology

The area traversed consists of fluviatile and marine sand, silts and limestone. The sand and silt are detrital deposits composed of clay-grade and sand – grade sized particles of calcareous material derived from coral reefs. For the first 8 kilometres a coral limestone ridge is present west of the road. The distance of the ridge from the road varies between a few hundred metres to a few kilometres. Several manually laboured open pits are established. However, the main coral limestone quarries operating with large crushers are located along the first 5 kilometres of the road.

### 2.4 Vegetation and Soil/Drainage Characteristics

The project road traverses bush land and thicket, changing to a more savannah characteristics near Bagamoyo. The soil cover is reddish brown stoneless sand with a drainage capability from moderate to good. The soil has a good resistance to erosion.

### 2.5 Rainfall

The main rain season is March to May, but interspersed with periods of sunshine. In November, short rains are experienced and intermittent rains may continue up to March. The mean, annual rainfall in the area varies between 800mm and 1400mm with the highest rainfall in the Kunduchi and Bagamoyo areas. The 10% probability of annual mean rainfall (i.e the amounts of rainfall that should be exceeded nine years in ten) showed a range of about 1000mm.

## 3 MATERIAL PROPERTIES

### 3.2 Aggregate Sources

There were three quarries in production along the project road, all with a high production capacity. Two quarries New Kunduchi, MECCO and Strabag/MECCO both situated at the junction Bagamoyo road turn off to Bahari and Kunduchi beach. Boko quarry is situated at about 1 kilometre off the existing road. In addition, on the same ridge (more to the northern end between kilometre 8 – 9) a few small-scale plots are in use for labour intensive hand crushing of the coral lime stone. In the same area a vast borrow pits have been open for both crushing and as natural unprocessed coral stone, however the site is now closed.

The coral lime stone complex that is about 9 kilometres in length (south – north direction) and approximately 300 – 700 m wide, is holding the three quarries with crusher capacity and the small labour intensive hand crushing plots. The complex is also the source for the cement factory production.

The coral lime stone present, underlying a 1.5 – 2.5 metres thick layer of reddish brown silty sand of fairly high plasticity (15 – 20 %) can in general be described as a three layer formation.

- The upper 1.0 – 1.5 metres consist of a white hard rock, which sometimes needs drilling and blasting before being hauled to the crusher. The layer has the presence of solution pipes that contain aeolian soil (similar type of material as overburden).
- The intermediate layer is weaker than the overlaying layer and varies in thickness from 4 – 7 metres and is more yellowish and may in certain areas have the presence of clay balls. This layer indicates to have a fairly high carbonate content as the broken stones leave white powder in the hands after being picked up. The layer can easily be ripped by a dozer.
- The bottom layer consists of greyish soft material with a large proportion of clay and is unsuitable for crushing.

The quarry at Boko at kilometre 5) seemed to contain higher proportion of plastic material than the quarries at Kunduchi.

The material produced at different quarries were as follows:

| | |
|---|---|
| New Kunduchi quarry, MECCO | 25mm, 12 – 20mm, 6 – 12mm and 0 6mm. |
| Strabarg/MECCO quarry | 10 – 20mm, 5 – 10mm, and 0 – 5mm |
| Boko quarry | 23 – 30mm, 12 – 23mm, 5 – 12mm, and 0 –5mm |

### 3.2 Sand Sources

River sand is obtainable in large quantities at kilometre 8.4 and kilometre 9.9 both at a distance between 3 to 5 kilometres offset from the existing road. The contractors were using both sources. River sand is also possible to excavate at kilometre 23.6, however the quantity available may be questionable.

At kilometre 43.0 (immediate outside Bagamoyo town) reddish brown sand is occurring in the road cut. The quantity available is uncertain, however it is believed that the sand extends along the ridge in east – west direction.

## 4 LABORATORY TEST RESULTS

### 4.1 Sampling and Testing of Aggregates

Each of the quarry sites having a crusher and the one worked labour intensive were visited and samples taken for testing at the Central Materials Laboratory in Dar es salaam. Sampled materials were taken from large stockpiles and sampled according to Standard Specifications.

The river sand source was sampled from a stockpile the contractor had formed in the dry period, to enable him to have access to sand in the rainy season when the riverbed is flooded.

The red brownish sand at kilometre 43.0 was sampled in a road cut after removing the exposed material in the cut face. The river sand at kilometre 9.9 is clean and grey in colour with angular quatzitic grains (100% passing a 5.0mm sieve). The red sand is slightly plastic with 100% of the material passing a 6.5mm sieve. Table 1 shows a summary of the properties of the aggregate.

**Table 1: Aggregate strength, shape and cleanness**

| TYPE OF TEST | SOURCES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | New Kunduchi, MECCO | | | | | Strabag/MECCO | | | Boko Estates Quarry | Bunju hand crushed (km. 8.5) |
| | Fraction (mm) | | | | | Fraction (mm) | | | Fraction (mm) | Fraction (mm) |
| | 0-6 | 6-12 | 6-12 2) | 12-20 1) 3) | >25 | 0-6 | 6-10 | 10-20 | 12-20 (4) | 20-38 |
| **ACV (kN)** | | | | 32 (37) | | | | 28 | 25 | 18 |
| **10% FACT (dry) (kN)** | | | | 97 (77) | | | | 156 | 97 | 70 |
| **10% FACT (wet) (kN)** | | | | 60 (82) | | | | 104 | | |
| **10% FACT ratio (%)** | | | | 90 | | | | | | |
| **LAA(%)** | | | | 41* 48** | | | | 39 | | |
| **Flakiness Index (%)** | | 32 | 37 | 22 | 33 | | 25 | 31 | 22 (50) | |
| **Dust (passing 0.0075mm)** | 87 | 1 | 12 | 1 | 1 | 16 | 9 | | | |
| **PI (%)** | 16 | | | | | | | | | |

**Note:**

1) Some clayey dusts cover. The aggregate origin from the top layer (upper two metres)
2) Some clayey dust cover
3) Value in brackets ( ) represents the whitish second layer * No clay dust
4) Value in brackets ( ) represents the 5 – 12mm fraction ** Some clay dust

The following comments are given on the aggregate strength values obtained from the different quarries. However, the samples were randomly executed and will therefore not be largely representative for the quarry area as a whole.

### 4.1.1 New Kunduchi, MECCO quarry

The aggregate strength shows that the upper 2 - 3m thick layer consists of harder rock than the underlying layers. Both the ACV and 10% FACT values support this. The aggregate strength for the upper layer shows an ACV, 10% FACT and LAA strength of 32, 97 and 41 respectively. These values are marginal to common Standard Specifications for crushed road base material (South Africa and Kenya). However, the 10% FACT ratio of 90% was surprisingly high. The lower laying rocks exhibit softer aggregate with ACV, 10% FACT and LAA strength of 37%, 77%, and 48% respectively.

#### 4.1.2 Strabag/MECCO quarry

This coral rock aggregate shows ACV, 10% FACT and LAA strength values of 28%, 156% and 39%. This material has a slightly higher strength than the New Kunduchi and MECCO quarry but there is a discrepancy between the ACV and 10% FACT common relationship.

#### 4.1.3 Boko estates quarry

The coral rock aggregate quality is of similar strength or slightly higher than for the Strabag/MECCO quarry with ACV and 10% FACT values of 25% and 97% respectively.

#### 4.1.4 Bunju local small quarry

The sampled material was hand crushed coral rock from the upper layer and exhibited strength values of 18% and 70% for ACV and 10% FACT tests respectively. The 10% FACT values were surprisingly low and correspond little with the ACV/10% FACT relationship. Visual inspection also confirms the high strength of this aggregate.

The coral stone aggregate tested are marginal for crushed stone base in terms of strength. The sampled quarries showed that the rock deposit strength decreased with depth, and that the aggregate strength varied considerably from one quarry site to the other.

### 4.2 Bitumen Stabilisation of Aggregates and Sand

#### 4.2.1 Coral rock aggregate/sand blend

Four different mixtures (all materials from New Kunduchi, MECCO quarry) has been considered viable for bitumen stabilisation. One mixture of only coral aggregate and the same mixture mixed with three different proportions of river sand were taken. The different mixtures were as follows:

- Crushed coral aggregate 50%/50% blend + 15% river sand
- Crushed coral aggregate 50%/50% blend + 25% river sand
- Crushed coral aggregate 50%/50% blend + 35% river sand
- Red sand only

The water absorption of the coral aggregate (ASTM) shows values of 1.9% and 2.5% for coarse material > 10mm and fine material between 2mm – 10mm respectively. Table 2 shows the aggregate characteristics for the different blends.

**Table 2: The soils characteristics of the different blends**

| Type of tests | Crushed Coral aggr. 50%/50% | Crushed coral aggr. 50%/50% + 15% river sand | Crushed Coral aggr. 50%/50% + 25% river sand |
|---|---|---|---|
| LL (%) | 22 | 18 | 17 |
| PI (%) | 8 | 5 | 6 |
| LS (%) | 6 | 4 | 4 |
| MDD ($Kg/m^3$) | 2096 | 2132 | 2068 |
| OMC (%) | 6.5 | 5.9 | 6.6 |
| $CBR_{soaked}$ at 98% MDD | 100+ | 100+ | 100+ |
| $CBR_{soaked}$ at 95% MDD | 100+ | 100+ | 82 |
| $CBR_{soaked}$ at 93% MDD | 93 | 87 | 71 |
| | | | |
| **Type of tests** | **Crushed Coral aggr. 50%/50%** | **Crushed coral aggr. 50%/50% + 15% river sand** | **Crushed Coral aggr. 50%/50% + 25% river sand** |
| **Increase in fines during compaction.** | | | |
| % pass 10mm | 23 | 3 | 12 |
| 5.0mm | 24 | 7 | 13 |
| 2.36mm | 20 | 5 | 17 |
| 0.6mm | 14 | 5 | 15 |
| 0.3mm | 11 | 5 | 15 |
| 0.150mm | 10 | 5 | 11 |
| 0.075mm | 0 | 3 | 9 |

### 4.2.2 Laboratory bitumen stabilisation

Two types of penetration grade bitumens were used, namely B 180 and B 250. Four points of bitumen content were used to determine the percentage of bitumen (by weight), preferably 4.0, 4.5, 5.5 and 6.5. It was considered important to apply bitumen in the laboratory adhered to similar concept as that used in the field (foamed bitumen). The foaming process in the laboratory was difficult to control accurately and consequently the achieved bitumen contents were outside what was actually desired.

The B 180 bitumen covered for the aggregate blend, 85% coral aggregate and 15% and a rather narrow gap in bitumen contents between 3.2% to 4.9% and where three points were between 3.2% and 3.4%. In practice, this only gives two points on the laboratory mix curve. For the blend of 75% and 25%, coral aggregate and sand respectively a wider spectre of pints were achieved, ranging from 3.2%to 5.2% and 8.9%.

The B 250 bitumen covered for both the aggregate blends 85%/15% and 75%/25% coral aggregate and sand respectively, a more desired spectre of points, achieving bitumen points between 3.4% to 5.5%.

The aggregate blend consisting of 65%/35% of coral aggregate and sand respectively were tested with only two points for both B 180 and B 250. This was due to shortage of aggregate material. the two points 5.3% and 8.1% for the B 180 bitumen and 3.55 and 4.6% for the B 250 bitumen may possibly be marginal to the optimum bitumen content.

## 5. DISCUSSION OF RESULTS

### 5.1 General

The following criteria have been used as the main parameters in the laboratory mix evaluation (*criteria from the Same- Himo full scale project 1991-93, Tanzania*):

- Flow between 2mm and 4 mm.
- Stability minimum 6000 N (cured for 24 hours at a temperature of 40$^0$C
- which also is a test temperature)
- E-modulus minimum 1600 MPa at 29$^0$C

It has been regarded that the flow will be an important parameter in the performance of the bitumen stabilised material, if the minimum stability criteria is maintained during the early stages (first six months after construction has been completed) of its performance. Importance of the parameter is governed by the strong wish of a highly flexible material. The minimum E-modulus of 1000 MPa (after seven days dry curing at a temperature of 29$^0$C) is based on experience showing that the E-mudulus increases with time, at least for the first two to three years. In consequence, the materials/layer capability in load distribution is secured at E-modulus requirement of minimum 1000 MPa.

### 5.2 Aggregate blend 85% coral stone and 15% sand

The aggregate blend using 85% coral stone and 15% sand show little difference between the two bitumen types (B 180 and B 250) at the various bitumen contents in terms of stability and flow. However, the type of bitumen seems to have influence on the E- modulus, although in a small scale. Using these criteria, the flow values indicate bitumen content between 3.4% to 5.2%. However, it is not advisable to use a bitumen content below 4.3% as this has been proved efficiency at the Same – Himo road trial. The stability requirement also indicates bitumen content of about 5% and this harmonises with the E-modulus requirement.

In conclusion, the aggregate blend of 85% coral stone and 15% sand can be stabilised at bitumen content between 4.3% to 5.0%. Tables 3 and 4 show the laboratory test results for the Bitumen type B 180 and B 250 mixed with 85% coral aggregate and 15% sand. Appendix 1 shows the graphical presentation of the laboratory results.

**Table 3 Bitumen type B 180 mixed with 85% coral aggregate and 15% sand**

| | Bitumen content in % by weight | | | |
|---|---|---|---|---|
| | 3.2 | 3.3 | 3.4 | 4.9 |
| Material type | Coral aggregate + 15% sand | | | |
| Dry density (kg/m$^3$) | 2103 | 2083 | 2065 | 2100 |
| Specific gravity of aggregate (kg/m$^3$) | 2570 | 2570 | 2570 | 2570 |
| Specific gravity of asphalt mix (kg/m$^3$) | 2448 | 2445 | 2441 | 2389 |
| Type of additive | Wetfix N 1.0% | Wetfix N 1.0% | Wetfix N 1.0% | Wetfix N 1.0% |
| Water content of mix (%) | 5.0 | 5.0 | 5.0 | 5.0 |
| Voids (%) | 14.1 | 14.8 | 15.4 | 12.1 |
| Marshall stability (N) * | 9797 | 8467 | 8950 | 5287 |
| Flow (mm) | 3.0 | 3.2 | 3.1 | 3.9 |
| Stiffness (N/mm) | 3259 | 2646 | 2895 | 1379 |
| E-modulus (MPa) ** | N/A | 2189 | 2736 | 1675 |
| Structural coefficient (Norwegian) *** | N/A | 2.72 | 2.94 | 2.49 |

NOTES:
* = Marshall values refer to curing for 24 hours at a temperature of 40 Celsius. Test temperature 40 Celsius.
** = E-modulus values refer to curing for 7 days at a temperature of 40 Celsius. Test temperature 29 Celcius.
*** = The following equation is used: Structural coefficient = 0.21 ** (0.33) (MPa)

**Table 4 Bitumen type B 250 mixed with 85% coral aggregate and 15% sand**

| | Bitumen content in % by weight | | | |
|---|---|---|---|---|
| | 3.4 | 3.9 | 4.0 | 5.4 |
| Material type | Coral aggregate + 15% sand | | | |
| Dry density (kg/m$^3$) | 2063 | 2089 | 2107 | 2107 |
| Specific gravity of aggregate (kg/m$^3$) | 2570 | 2570 | 2570 | 2570 |
| Specific gravity of asphalt mix (kg/m$^3$) | 2439 | 2423 | 2419 | 2370 |
| Type of additive | Wetfix N 1.0% | Wetfix N 1.0% | Wetfix N 1.0% | Wetfix N 1.0% |
| Water content of mix (%) | 5.0 | 5.0 | 5.0 | 5.0 |
| Voids (%) | 15.4 | 13.8 | 12.9 | 11.1 |
| Marshall stability (N) * | 11090 | 7283 | 7120 | 4267 |
| Flow (mm) | 2.6 | 3.7 | 3.2 | 3.9 |
| Stiffness (N/mm) | 4211 | 1991 | 2256 | 1097 |
| E-modulus (Mpa) ** | 2602 | 557 | 1705 | 1326 |
| Structural coefficient (Norwegian) *** | 2.89 | 2.43 | 2.51 | 2.31 |

NOTES:
* = Marshall values refer to curing for 24 hours at a temperature of 40 Celsius. Test temperature 40 Celsius.
** = E-modulus values refer to curing for 7 days at a temperature of 40 Celsius. Test temperature 29 Celcius.
*** = the following equation is used: Structural coefficient = 0.21 ** (0.33) (MPa)

## 5.3 Aggregate blend 75% coral stone and 25% sand

This aggregate blend distinguishes between the two types of bitumen used. The flow and stability requirements for the B 180 grade are met at bitumen content between 4% and 5.5% respectively. For the B 250 grade the stability requirement is met at bitumen content of less than 5%, and the flow requirement of greater than 5%. Bitumen content of 5.0% meets both stability and flow requirement, however close to the minimum values. In conclusion this blend can also be bitumen stabilised provided the bitumen content is approximately between 4.3% and 5.0%. Tables 5 and 6 shows the laboratory test results for the Bitumen type B 180 and B 250 mixed with 75% coral aggregate. Appendix 1 shows the graphical presentation of the laboratory results.5% sand.

**Table 5 Bitumen type B 180 mixed with 75% coral aggregate and 25% sand**

| | Bitumen content in % by weight | | | |
|---|---|---|---|---|
| | 3.2 | 3.3 | 5.2 | 8.9 |
| Material type | Coral aggregate + 25% sand | | | |
| Dry density (kg/m$^3$) | 2081 | 2072 | 2084 | 2079 |
| Specific gravity of aggregate (kg/m$^3$) | 2570 | 2570 | 2570 | 2570 |
| Specific gravity of asphalt mix (kg/m$^3$) | 2448 | 2446 | 2379 | 2257 |
| Type of additive | Wetfix N 1.0% | Wetfix N 1.0% | Wetfix N 1.0% | Wetfix N 1.0% |
| Water content of mix (%) | 5.0 | 5.0 | 5.0 | 5.0 |
| Voids (%) | 15.0 | 15.3 | 12.4 | 7.9 |
| Marshall stability (N) * | 8153 | 9220 | 207 | 973 |
| Flow (mm) | 2.9 | 3.2 | 3.4 | 6.7 |
| Stiffness (N/mm) | 2784 | 2882 | 1547 | 145 |
| E-modulus (MPa) ** | 2138 | 2907 | 1700 | 330 |
| Structural coefficient (Norwegian) *** | 2.71 | 3.00 | 2.51 | 1.45 |

NOTES:
* = Marshall values refer to curing for 24 hours at a temperature of 40 Celsius. Test temperature 40 Celsius.
** = E-modulus values refer to curing for 7 days at a temperature of 40 Celsius. Test temperature 29 Celcius.
*** = The following equation is used: Structural coefficient = 0.21 ** (0.33) (MPa)

**Table 6: Bitumen type B 250 mixed with 75% coral aggregate and 25% sand**

| | Bitumen content in % by weight | | | |
|---|---|---|---|---|
| | 3.8 | 4.7 | 5.5 | |
| Material type | Coral aggregate + 35% sand | | | |
| Dry density (kg/m$^3$) | 2065 | 2078 | 2105 | |
| Specific gravity of aggregate (kg/m$^3$) | 2570 | 2570 | 2570 | |
| Specific gravity of asphalt mix (kg/m$^3$) | 2427 | 2394 | 2368 | |
| Type of additive | Wetfix N 1.0% | Wetfix N 1.0% | Wetfix N 1.0% | |
| Water content of mix (%) | 5.0 | 5.0 | 5.0 | |
| Voids (%) | 14.9 | 13.2 | 11.1 | |
| Marshall stability (N) * | 6870 | 5253 | 4023 | |
| Flow (mm) | 2.8 | 2.8 | 3.4 | |
| Stiffness (N/mm) | 2429 | 1871 | 1196 | |
| E-modulus (Mpa) ** | 1557 | 1307 | 1121 | |
| Structural coefficient (Norwegian) *** | 2.43 | 2.30 | 2.18 | |

NOTES:
* = Marshall values refer to curing for 24 hours at a temperature of 40 Celsius. Test temperature 40 Celsius.
** = E-modulus values refer to curing for 7 days at a temperature of 40 Celsius. Test temperature 29 Celcius.
*** = The following equation is used: Structural coefficient = 0.21 ** (0.33) (MPa)

## 5.4 Aggregate blend 65% coral stone and 35% sand

Because of the shortage of material, only two points were determined, and in addition the two types of bitumen were mixed in at rather low content (3.4% and 4.6%) and at a higher bitumen content (8.1%). Both the stability and flow requirements are met for the B 180 grade at bitumen content <5.4% and <6.0% respectively (based on extrapolation). B 250 grade meets the stability requirements for the two bitumen contents tested, while the flow requirement is met at bitumen content of greater than 5.0%. Tables 7 and 8 shows the laboratory test results for the Bitumen type B 180 and B 250 mixed with 65% coral aggregate and 35% sand. Appendix 2 shows the graphical presentation of the laboratory results.

**Table 7 Bitumen type B 180 mixed with 65% coral aggregate and 35% sand**

| | Bitumen content in % by weight | | | |
|---|---|---|---|---|
| | 5.3 | 5.1 | | |
| Material type | Coral aggregate + 35% sand | | | |
| Dry density (kg/m$^3$) | 2091 | 2087 | | |
| Specific gravity of aggregate (kg/m$^3$) | 2570 | 2570 | | |
| Specific gravity of asphalt mix (kg/m$^3$) | 2376 | 2314 | | |
| Type of additive | Wetfix N 1.0% | Wetfix N 1.0% | | |
| Water content of mix (%) | 5.0 | 5.0 | | |
| Voids (%) | 12.0 | 9.8 | | |
| Marshall stability (N) * | 4713 | 1920 | | |
| Flow (mm) | 3.4 | 6.3 | | |
| Stiffness (N/mm) | 1384 | 309 | | |
| E-modulus (MPa) ** | 1606 | 620 | | |
| Structural coefficient (Norwegian) *** | 2.46 | 1.79 | | |

NOTES:
* = Marshall values refer to curing for 24 hours at a temperature of 40 Celsius. Test temperature 40 Celsius.
** = E-modulus values refer to curing for 7 days at a temperature of 40 Celsius. Test temperature 29 Celcius.
*** = The following equation is used: Structural coefficient = 0.21 ** (0.33) (MPa)

**Table 8 Bitumen type B 250 mixed with 65% coral aggregate and 35% sand**

| | Bitumen content in % by weight | | | |
|---|---|---|---|---|
| | 3.5 | 4.6 | 5.5 | |
| Material type | Coral aggregate + 35% sand | | | |
| Dry density (kg/m$^3$) | 2059 | 2085 | | |
| Specific gravity of aggregate (kg/m$^3$) | 2570 | 2570 | | |
| Specific gravity of asphalt mix (kg/m$^3$) | 2437 | 2399 | | |
| Type of additive | Wetfix N 1.0% | Wetfix N 1.0% | | |
| Water content of mix (%) | 5.0 | 5.0 | | |
| Voids (%) | 15.5 | 13.1 | | |
| Marshall stability (N) * | 5183 | 7030 | | |
| Flow (mm) | 2.4 | 2.8 | | |
| Stiffness (N/mm) | 2134 | 2489 | | |
| E-modulus (Mpa) ** | 1615 | 1700 | | |
| Structural coefficient (Norwegian) *** | 2.46 | 2.51 | | |

NOTES:
* = Marshall values refer to curing for 24 hours at a temperature of 40 Celsius. Test temperature 40 Celsius.
** = E-modulus values refer to curing for 7 days at a temperature of 40 Celsius. Test temperature 29 Celcius.
*** = The following equation is used: Structural coefficient = 0.21 ** (0.33) (MPa)

## 5.5 Red Sand

The fine-grained sand (about 100% passing 1.0 mm sieve) was tested to investigate a preliminary possible bitumen stabilisation for the sampled source and other similar sources. However due to shortage of material only two bitumen contents were determined using the B 80/100 bitumen type and only one bitumen content determination for the B 250 bitumen type. The test results indicate a bitumen content of about 6.0% to reach a flow value between 3.0mm - 4.0mm when using B 80/100 bitumen type. The B 250 bitumen indicates (based only on one point, 4.8%) to be too soft and may therefore give stability values below what is considered necessary for a sand bitumen stabilised layer. A more thorough laboratory investigation will be required before a firmer conclusion can be taken. Table 9 shows the laboratory test results for the Bitumen type B 180 and B 250 mixed with red sand. Appendix 2 shows the graphical presentation of the laboratory results.

**Table 9: Bitumen type B 80/100 and B 250 mixed with red sand .**

| | Bitumen content in % by weight | | | |
|---|---|---|---|---|
| | 4.0 | 5.3 | 4.8 | |
| Material type | | Red sand | | |
| Dry density (kg/m³)<br>Specific gravity of aggregate (kg/m³)<br>Specific gravity of asphalt mix (kg/m³) | 1809<br>2670<br>2502 | 1864<br>2670<br>2456 | 1853<br>260<br>2474 | |
| Type of additive | Wetfix N 1.0% | Wetfix N 1.0% | Wetfix N 1.0% | |
| Water content of mix (%) | 10.0 | 10.0 | 10.0 | |
| Voids (%) | 27.7 | 24.1 | 25.1 | |
| Marshall stability (N) * | 13110 | 8680 | 5810 | |
| Flow (mm) | 2.3 | 2.6 | 2.5 | |
| Stiffness (N/mm) | 5700 | 3340 | 2324 | |
| E-modulus (Mpa) ** | 1985 | 1792 | 967 | |
| Structural coefficient (Norwegian) *** | 2.64 | 2.55 | 2.07 | |

NOTES:
* = Marshall values refer to curing for 24 hours at a temperature of 40 Celsius. Test temperature 40 Celsius.
** = E-modulus values refer to curing for 7 days at a temperature of 40 Celsius. Test temperature 29 Celcius.
*** = The following equation is used: Structural coefficient = 0.21 ** (0.33) (MPa)

### 5.6 Coral Stone Aggregate Use as Neat Base Course Layer

The neat coral stone aggregates are marginal to be used neat as a crushed stone base layer. The inhomogeneity of the coral aggregate will probably require rather rigid quality assurance if regarded used as such. Even so, the normal requirements adopted will most probably have to be lowered. However, regarding the cost to haul aggregate over long distances, this option should be carefully assessed.

## 6. CONCLUSIONS

1) The laboratory test results indicate that all the coral aggregate/sand blends were used in the laboratory testing can be stabilised with foamed bitumen of type B 180 or B 250 at designed bitumen content.
2) Both B 180 and B 250 penetration grade bitumen can be used for stabilisation purposes. The preferable optimum bitumen content seems to be in the range between 4.3% and 5.4% depending on the proportions of sand mixed in, and possibly also the type of bitumen. The blends tested are satisfying the immersion index requirements of greater than 60%.
3) Bitumen content on the higher side may be more preferable in order to compensate for the porous coral aggregate. This could possibly be beneficial as the water absorption is between 1.9% and 2.5%. However, a more detailed laboratory study is required to decide more accurate optimum bitumen content.
4) The long-term durability of foamed bitumen stabilised coral aggregate has not been investigated. However, using a bitumen content that caters for the porosity of the aggregate, the performance should be similar to other foamed bitumen stabilisation mixes.
5) Trial road sections should be identified for further investigations and implementation of stabilisation technique before massive scale use of the material.

6) The neat coral stone aggregate strength could probably be considered used neat as a crushed stone base layer, although the materials are somewhat marginal in strength. However, the inhomogeneity of the coral aggregate will probably require a rather rigid quality assurance if regarded used as crushed stone base. Hence, the required volume to be processed will have to be increased considerably, and may therefore not be economically feasible.

## 7. SUMMARY

The use of coral stones in the base course could possibly imply a substantial save in transport cost of the aggregate as normally acceptable materials are not available in the vicinity of the coastal zone. Through Institutional Co-operation MoW/CML and NPRA/NRRL was decided to carry out preliminary investigation along the Dar Es Salaam – Bagamoyo road to identify the suitability to bitumen stabilised coral aggregates using cold foaming technique.

The laboratory tests performed, clearly showed that bitumen stabilisation using the cold foaming technique is possible using coral stone aggregate mix with some river sands. The two bitumen types B180 and B 250 penetration grade used in the Laboratory test work are both suitable as stabilising agent at a bitumen content of between 4.3% to 5.4%.

The neat coral stone aggregates are marginal to be used neat as a crushed stone base layer. The inhomogeneity of the coral aggregate will probably require rather rigid quality assurance if regarded used as such. Even so, the normal requirements adopted will most probably have to be lowered. However, regarding the cost to haul aggregate over long distances, this option should be carefully assessed.

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