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1.0 INTRODUCTION

1.1 Background

Budgetary constraints for the provision of sealed low volume roads both in the industrialized and developing countries have for many years forced the road engineers to search and develop innovative methods of road design, construction and maintenance in order to maximize the utilisation of the available funds. In this effort, very often consideration has to be given to the use of local materials, although the material may be nonstandard or marginal to the more rigid specifications. Strict adherence to the more conventional standard specifications would either prohibit the project or make it unnecessarily costly.

One area where cost savings can be made is with careful consideration in the choice of bituminous surfacing. By innovation-oriented approach the Otta Seal concept was developed and has for more than three decades proved to be very cost effective both in Scandinavia, Iceland, East and Southern Africa and partly also in Bangladesh. Unfortunately, its use is not as widespread as it could be, which is probably due to lack of public information regarding it’s properties, design, construction and performance.

The main purpose of this paper is to summarise the experience that has been gained in the use of the Otta Seal for the last three decades in a global perspective. By doing so, it is hoped that this dissemination of experience will assist other engineers in considering this type of surfacing in other similar environments.

2.0 DETAILS OF THE OTTA SEAL

2.1 Origin and Application

In the early sixties about 50% or 40 000 km of the total public roads in Norway were unpaved gravel roads with low bearing capacity, carrying an AADT between 50 - 500 vehicles (Thurmann-Moe 1979). During the spring thaw period many road sections were unpassable for both light and heavy vehicles. These roads, at that time, according to the current practise were considered to be completely reconstructed prior to applying bituminous surfacing. However, the progress of the rehabilitation programme was slow due to budgetary and heavy construction plant constraints. In 1963 the Norwegian Road Authorities had identified a need to develop a method or treatment that could effectively improve the quality of the gravel roads to a cost equal to the gravel road maintenance. The two main goals, based on economical and technical aspects that had to be achieved were as follows:

- The investments should be earned back in a few years through reduced maintenance cost only.
- The road user should find the quality and performance of the surface close to other conventional bituminous surfacing.

In order to satisfy these two overruling main goals the surfacing should preferably comply with the following requirements:

- Be cheap and easy to carry out anywhere in the country.
- Utilise locally available screened natural aggregates.
- Be impervious to prevent water into the water susceptible base material.
- Be very flexible, durable and easy to maintain.
In 1963 the Norwegian Road Research Laboratory (NRRL) was commissioned to develop a bituminous surface treatment that applied to a situation the before mentioned economical and technical requirements (Olsen et al. 1984). During the years 1963-65 trials were carried out in the Otta Valley where its name derives from.

The construction operations for an Otta Seal are very similar to a spray-chip seal using single sized aggregate. However, with the use of graded aggregate (including fines) and a fairly high spray rate of low viscosity binders, its maturation is different and takes a longer time. The differences in brief between the two types of surfaces is given below:

- An Otta Seal is formed by placing graded aggregates(fines and dust included) on a comparatively soft binder which by rolling and trafficking works its way upwards through the many particle aggregate interstices. The seal can be trafficking immediately after rolling and its final appearance is formed after 4 - 8 weeks time. A primed base is normally not required.

- A chip seal is constructed by using single sized aggregate (clean and dust free) placed shoulder to shoulder on a comparatively hard binder, with the main objective of “gluing” the latter to the former. Traffic is not allowed on the surfacing before the binder is finally set, normally after one week. A primed base is normally required.

Initially intended for use as a temporary “bituminous maintenance seal” for gravel roads its good performance led to its adoption also for newly constructed and existing bituminous roads for both low and medium traffic situations. Since its inception, the method has had an extended use, from being an economical maintenance seal on gravel roads, to a fully fledged bituminous surfacing. This surfacing concept is today considered to have no other limitations regarding traffic volumes than one would apply to any sprayed bituminous surfacing. However, the lack of rational methods to design Otta Seals due to its high flexibility in both aggregates, softness of bitumen and spray rates has probably limited the use of this surfacing type.

### 2.2 Aggregates

#### 2.2.1 Material sources

The main advantage of an Otta Seal is the flexibility and variety of materials that can be used. Other more conventional type of surface treatment such as single sized chipping has rather rigid specifications regarding grading, cleanness, shape and mechanical strength which require operation of a crushing plant that may result in costly solutions that in many cases will be difficult to justify. The following typical materials have been used as aggregate for Otta Seals with excellent performance:

- Moraine, screened only and/or crushed.
- Crushed rock, Gabbro, Basalt, Silcrete and weak Sand stone.
- Basalt gravel, partly screened/crushed.
- Coral stone, screened and crushed.
- Lake gravels, both screened and crushed (oversize stones).
- Laterite and Decomposed Granite, screened to remove oversize material.

It is of course desirable to use material of best mechanical strength in the production of graded aggregate, and this will be more important if crushing is to take place. However,
excellent performance of aggregate with crushing strength far below what is normally accepted for more conventional bituminous seals have been monitored in Botswana and Kenya for more than 12 years with an AADT of 300. Materials used were of inferior quality with low crushing strength. However, the approach of producing graded aggregates may be described as to device the best way of using whatever source of material available in combination with an appropriate choice of binders.

2.2.2 Envelopes of Grading
Both uncrushed and crushed material or a mixture of these may be used. The grading curve should fall within and as parallel to the envelope detailed in Figure 1. It should be noted that the grading requirements are rather wide, however the preferred maximum size is 16mm (19mm) and maximum amounts of fines (>0.075 mm) should not exceed 10%, although fines in excess of 14% have performed well for many years in Botswana (Overby 1982). Very often the grading of natural occurring gravel falls within this envelope, with the exception of oversize material that has to be removed by screening.

![Figure 1: Grading Envelope Curves for Graded Aggregates used in Otta Seal](image)

For roads with low traffic (AADT < 100) it is preferred to be on the “coarse” side of the envelope (less fines), while for traffic in the range of more than 500 vehicles per day one
should aspire to be in the higher side of the envelope (more fines).

Requirement for flakiness is not specified for Otta Seals utilising natural gravel, however when crushed rock is used, the weighted flakiness index on the 13,2 mm, 9,5 mm and 6,7 mm should preferably not exceed 30 (Overby 1982).

2.3 Prime and Binders

2.3.1 Prime
Normally it is not necessary to prime the base prior to spraying the binder for the Otta Seal. However, for base material consisting of calcareous materials (calcrete varying from nodular (coarse) to calcified sand (fine) which tends to yield a high absorbent of bitumen a prime will be beneficial. Both bitumen and tar can be used for this purpose and common viscosity range is between 45-30 cSt at an application rate between 0,8-1,0 l/m².

2.3.2 Binders
The type of binder used will depend largely on the aggregate used, as this could significantly affect the performance of the seal. It is therefore of paramount importance to select a correct viscosity range of the binder at the time of construction. Usually ordinary cut back bitumen’s MC 800 or MC 3000 are used, however, 150/200 pen. bitumens have been successfully used in Botswana. In Scandinavia other denominations are used but their viscosity ranges are similar. Cutting back the bitumen on site from 60/80 and 150/200 pen. bitumen has been successfully carried out, by both adding cutters (paraffin or diesel) and fluxes oil (engine oil) to improve the overall durability of the binder (Overby 1983 and 1996).

Emulsions have been used in Scandinavia but in general this has not proved to be too successful, mainly because of the rapid setting of the emulsion (quick water evaporation) and stiff bitumen base products which do not allow the bitumen to coat the aggregate layer many particles thick. In principle, emulsions can be designed according to their purpose for use, but this has been a difficult problem to overcome, at least in Norway.

Tar has not been used in Otta Seals, and the reason for this is that the tar tends to harden rapidly and hence, not supporting the flexibility required.

2.4 Design and Construction

2.4.1 General
From its early beginning the Otta Seal was either applied as a single or double seal using the same grading and binder application for the first and second seals. Today, this is still the practise with only minor adjustments. However, in one African country, namely Botswana a variety of combination using the Otta Seal approach has been constructed successfully (Pinard and Obika 1997). Apart from the normal single and double seals' Botswana has split the grading into two fractions, more “open” and “dense” graded aggregate, respectively. Very fine graded Kalahari sand (100% passing the 1,00 mm sieve) which is easily available over a large part of the country, is in many cases, and in particular for single Otta seals, used as Sand seal cover in order to ensure proper aggregate retainment and to delay the ageing of the Otta Seal binder.

2.4.2 Design
Compared to other types of surfacing the design of an Otta Seal is simple, but requires an empirical approach-based experience in the formulation of selecting appropriate binder-
aggregate combination and application rates. The factors that influence this formulation are:

- Aggregate type and grading
- Traffic intensity and proportion of heavy vehicles
- Porosity of base or condition of old surfacing
- Rolling equipment and procedure
- Weather conditions during construction

However, in saying so the following general guide for spray rates can be given:

<table>
<thead>
<tr>
<th>AADT</th>
<th>Spray Rates (hot)</th>
<th>l/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 100</td>
<td>1.8 - 2.2</td>
<td></td>
</tr>
<tr>
<td>100 - 500</td>
<td>1.8 - 2.0</td>
<td></td>
</tr>
<tr>
<td>&gt; 500</td>
<td>1.6 - 1.8</td>
<td></td>
</tr>
</tbody>
</table>

In Africa it has been common practice reducing the binder application rate for the second seal with 10% compared to the first seal. While in Scandinavia the application rate for the second seal is similar to the first seal or slightly above.

In Scandinavia adhesion additives/wetting agents are normally used at a quantity of 0.8% by weight of bitumen. Reported from elsewhere, Kenya and Bangladesh (Mariki et al. 1995 and LGED 1994), Otta Seals have preformed excellently without any adhesion additives.

2.4.3 Construction of an Otta Seal
The construction operations for an Otta Seal are similar to those of a conventional bituminous surface treatment by spraying binder followed by the spreading of aggregate. Different from these more conventional surface treatments is that the binder for the first layer of an Otta Seal very often is sprayed on a non-primed base. In order to bind the dust on the top of the base, and also open the top base upper pores, hence, it is absolutely necessary to water the base prior to spraying the binder. After watering ample time should be given to allow the base to dry into a dampened stage with open pores allowing the binder to penetrate and ensure a good bond to the base. On a dry and dusty base a contraction behaviour of the binder will take place, resulting in uncovered spots in the sprayed layer of bitumen, and eventually resulting in potholing.

The aggregates are normally applied by self-propelled or truck mounted chip spreaders. However, spreading the aggregate by hand, both from a reversing truck or from staggered aggregate stockpiles along the road have successfully been used (Overby 1982 and 1996). In the latter, each run of the bitumen sprayed sections should be shorter.

In constructing an Otta Seal emphasis should be concentrated, but not limited, to the following:

1. Pneumatic rollers are essential as their ability to knead the binder upwards the many particles- thick- aggregate- layer is superior to the steel rollers. At the time the initial rolling with the pneumatic equipment is completed commercial traffic should be allowed on the surfaced area as this will assist further in the kneading process of the binder/aggregate mix. A maximum speed limit should not exceed 40 - 50 km/hour the following first weeks. (In the absence of pneumatic rollers, compaction has been successfully carried out by the use of loaded trucks following a set rolling pattern covering the entire surfaced area (Overby 1982 and 1996).
2. The following two days excessive rolling by pneumatic roller(s) shall take place in order to ensure that all particles embedded in the binder are properly coated. It should be noted that it is not possible to over-roll an Otta Seal for the first two-three days after construction. The more rolling, the better the quality of the seal that is formed.

3. The initial occurrence of signs of bleeding and isolated fatty spots should not be any cause of concern, and can be blinded off with finer aggregate and preferably rolled into the surfacing. Signs of slight bleeding confirm that the ratio aggregate/binder has been optimal.

4. A minimum period of three months should normally elapse between the construction of the first and second layers. This is to allow as much traffic as possible before evaporation of the cutters is completed. During this period the surfacing becomes more settled and the exposed wheel paths (aggregate blown out by traffic) shows a “premix” like appearance. A newly constructed Otta Seal may be dusty and liable to flying stones at least for the first weeks after construction.

5. Excess cover material is always needed in the case when constructing an Otta Seal, and it is important to ensure that the aggregates are excessively applied (ref. point 4). After the elapse period is over excessive material should be broomed off and collected. This surplus material should be added to the second seal or be added to the material forming the future first seal. In the case of a second seal bitumen from the first layer shall by then be visible over the entire surface width.

6. The Otta Seal concept make allowances for a variety of aggregate gradings and cannot be directly designed by a general rational method (as for a chip seal). It’s design must therefore be tailored to the local environment in terms of the aggregate and binder available, type of traffic and climate. Local experience and sound judgement by the engineer and not at least the work foreman at the start of the sealing work (adjustment may often be required) will be essential to achieve a satisfactory result. However, saying so it is experienced that with only 75-80% successful construction achievements for an Otta Seal, one can still obtain close to maximum performance of the seal. Contrary, for a chip seal under equal construction conditions the performance of the chip seal would have been far from satisfactory, probably being described as completely ruined.

A rule of a thumb is to assume a good result when one can see bitumen being pressed up in-between the aggregates, sparsely distributed in the wheel tracks of the chip spreader or truck wheels. A good result is further confirmed if a “premix” like appearance is formed in the wheel paths after 2 - 4 weeks trafficking.

**Figure 2: Mechanisms of a Single Otta Seal in comparison to a Single Chip Seal**
3.0 CHARACTERISTICS OF AN OTTA SEAL

3.1 Performance Characteristics

The texture of an Otta seal is playing a vital role in its performance, which again is related to its resistance to abrasion. This in relation to the cold climates prevailing in the Scandinavian countries where studded tires are common during the winter. The dense textures of the Otta Seal as formed by many particles thick layer of aggregates where the interstices are filled with comparatively soft bitumen has been found to be fairly resistant to wear and tear from the studded tires. Also, in Scandinavia, on roads with inferior bearing capacity during the thaw period the Otta Seal is often preferred. This is mainly because of its flexible behaviour and easiness to both construct and maintain. In hotter climates such as Africa where binder oxidation and following brittleness are caused by solar radiation, timely and appropriate maintenance/resealing frequency has to be adopted to prevent disintegration of the bituminous seal. It seems that the close-textured grading as formed by the Otta Seal concept is less susceptible to binder ageing, and hence may be described as more durable than the more open-textured chip-seal surfacing.

From the behavioured mechanism of of the Otta Seal, and from visual evidence of performance under different climatic conditions (ranging from freezing cold -40°C, to mild and wet, from temperate hot and wet to very hot and dry), varying levels of traffic, different type of aggregates (varies from weak natural occurring material to crushed hard rock) and different construction approaches (labour intensively to very mechanised plant operations) it seems that the Otta Seals have no other limitation regarding traffic volumes than one would apply to any other sprayed bituminous surfacing types.

3.2 Economic Considerations

The cost of construction will vary considerably depending on a variety of factors such as availability of materials (crushing or only screening required), remoteness of construction site, haulage distance and cost of plant and labours among others. Such costs will vary from country to country, but the interesting point is the relative cost of constructing and maintaining an Otta Seal versus a conventional bituminous seal (Chip seal) under similar conditions. The following factors are predominant with regard to cost savings:

- Reduced cost in aggregate production (only screening may be required, and if
crushing is necessary most of what is crushed is used, including the fines.

- Hauling cost is reduced because of the utilisation of local gravels.
- In most cases' prime is omitted.
- In many cases surfacing operations cost is reduced.

In general, an Otta Seal gives cost saving in the magnitude of 20%, although cost savings in order of 35-40% has been reported (Hansen et al 1980), compared to the more conventional chip seal. For about 10 years back, the cost figures in Norway showed that in average, a single Otta Seal applied directly on a secondary gravel road would break even with the accumulated maintenance cost of a gravel road after 3 - 4 years (Olsen et al. 1984). Similar for a double Otta Seal the break even would be after 5 -6 years.

Table 1 and 2 shows relative advantages/disadvantages and the contrast qualitatively for the Otta Seal over conventional chip seals, respectively.

### 4.0 THE REPORTED GLOBAL USE OF OTTA SEAL

#### 4.1 General

The use of the Otta Seal concepts that have been reported summarises into seven countries whereof two from Scandinavia (Norway, Sweden), Iceland, three from East and Southern Africa (Kenya, Botswana and Zimbabwe) and one country in Asia (Bangladesh). Apart from the Scandinavian countries the Otta Seal applications have always been introduced by Donor Agency involvement, and never through Consultancy services or International Bank financed projects. The reason for this may be several, but the following may be the general constrains:

- Firstly - No rational design procedure available.
- Secondly - The consultants and contractors do not know the Otta Seal applications, and hence they are both reluctant to specify and tender, and if tendering, they very often use conventional chip seal prices.
- Thirdly - Most of the work, although not all, has been done by in-house construction units.

Nevertheless, in Botswana (Pinard and Obika 1997) this is changing as the Roads Department put pressure to both the consultants and the contractors to make reliable cost comparisons.

#### 4.2 The Otta Seal Global Experience

##### 4.2.1 Norway

Since its development in the early 1960's the Otta Seal concept was heavily adhered to for the following 30 years. By 1985 more than 12 000 km of road had been surfaced using the Otta Seal. This was about 20% of the total paved road network. Service life and performance depends heavily on local conditions (as always, not specifically for the Otta Seal), but it is the experience that on a road with an AADT of 1000 and a Benkelman beam deflection (80 kN) of 1,25mm a double Otta Seal will give excellent performance for 10 years or more. For a single seal a service life of 5 - 6 years is common.

As per today about 2000 km of the bituminised road network is surfaced by a Single Otta
Seal, and whereof 25% is placed on primary roads and the remaining 75% on the secondary roads. Similarly for the Double Otta Seals, today 2000 km is surfaced, and about 50% have been placed on the primary road network. In total 4000 km are today surfaced by an Otta Seal, this count for about 10% of the total bituminised road network in Norway (26 000 km main and 18 000 km secondary roads). It is worth while to notice that 65 km (single) and 120 km (double) of the Otta Seals have per today been in service for more than 20 years and are still performing satisfactorily. The majority of these road lengths apply for the secondary road network.

The general specifications used in for Otta Seals in Norway are as follows:

Traffic : AADT< 2000
Aggregates: Moraine gravel, both screened and crushed or in combination are used. Gabbros are a common rock type used. Experience has shown that a proportion of 30% crushed material gives the best performance.
Aggregate class. 1 - 3
Flakiness/friability. < 1,5
Grading envelope in the lower part of the envelope as showed in Figure 1. Material passing 4,00 mm shall not be less than 35%. Material passing 0,075 mm shall not exceed 10%.

Application rate 1st. seal 0-16 mm 22-30 kg/m². 2nd. Seal 0-11 mm 18-20 kg/m² (often preferred as second seal)

Bitumen: Emulsion BE 70M, of the following bitumen types MB 3000 - MB 10 000
Medium curing bitumen, BL 1500M - BL 4500 M
Application rates, BL between 1,7 - 1,9 l/m². BE between 1,9 - 2,1 l/m²

Adhesion agents: Always, 0,8% by weight of bitumen is used.

4.2.2 Sweden
The Otta Seal was introduced in Sweden around 1985. The term for the Otta Seal in Sweden is Y1G and in general their experience is similar to those from Norway. As per today about 4000 km of roads have been bituminised by using the Otta Seal concept. A large proportion of these roads are secondary gravel roads in the northern and eastern (forest counties) parts of Sweden that are upgraded to a bituminous standard. The Swedish Road Authority has also used the single seal concept as dust binding precautions on gravel roads without any form of pavement strengthening (life expectancy 3 - 5 years). As quoted from the Swedish Road Authorities (Overby 1997) the general experiences have been and is still good. However, the reorganisation of the Swedish Road Authorities and younger engineers have led to the fact that this type of surfacing has decreased over the recent years. In many cases
the Otta Seal has been placed on poorly drained gravel roads with insufficient bearing capacity with the consequences that the seal has failed much earlier than anticipated.

The general specifications used in for Otta Seal (Y1G) are very similar as for those in Norway. However, maximum AADT is reduced to AADT < 500.

4.2.3 Iceland
In 1978 the Otta Seal was introduced in Iceland as an alternative to plant mixed oil-gravel on low traffic roads. Because of large distances and a rather limited market, stationary or even mobile asphaltic plants have not been feasible, and hence the Otta Seal has been manifested as a cost effective and technically appropriate solution for low traffic roads and especially in the remote areas. Per today more than 2000 km have been covered with a double Otta Seal, and its performance is rated to be very good (Overby 1997).

The most common aggregate used is basaltic gravel with a crushed surface fracture of minimum 40% for a traffic volume of AADT > 1000, and minimum 20% for AADT < 1000. The grading envelope is similar as for Figure 1. The strength of the aggregate refers to the LAA value, where the following are adopted in the specifications: AADT < 200 max. LLA values of <30%. For AADT figures of 200-1000, 1000 - >2000 the following LAA values apply, respectively < 25%, and < 20%. The most common bitumen used is BL 1500R at an application rate of 2,0 l/m².

4.2.4 Kenya
In the middle of the 1970's the Governments of Kenya and Norway agreed to construct a 290 km long gravel road on a 50/50 shear basis. The project was linked to the new Turkana Road in the arid/semiarid North western part of Kenya. Following the completion of the road, maintenance problems arose in this climate. A bituminous surfacing was discussed, and it was decided to apply a double Otta Seal. During the period 1978 - 1984 the entire road length had been surfaced using MC 3000 as binder and natural screened (uncrushed) quartzitic gravel as surfacing aggregate (ACV/LAA 32/49). Base course thickness of min. 130 mm with materials requirements of a min. CBR soaked of 50 (but single values of 30 were accepted) and max. PI of 20 was adhered to. Benkelman Beam deflection (80 kN) of less than 1,25 mm was regarded as acceptable prior to surfacing (Hansen 1983). No prime was applied for any of the road sections, but an adhesive agent was always used.

A study carried out (Mariki et al 1995) quoted the following:

Turkana Road at Marich Pass was completed in 1978 and as per today with an accumulated AADT of 0,96 mill. and E 80 kN 4,0 mill. Annual mean rainfall 1000mm. Part of the section had been resealed (third seal) with Otta Seal using similar quartzitic gravel used for more than 15 years back. Apart from some stone loss the performance was good.

Turkwell Gorge - Lodwar was completed in 1980. As per today with an accumulative AADT of 0,66 mill. and an accumulated E 80 kN of 2,1 mill. Annual mean rainfall 300-400mm. About half of the road had been resealed using the Otta Seal, and its performance was good. Those section that had not been resealed (being in service for more than 17 years without any maintenance) had reached the end of it’s service life as extensive potholing prevailed. The section completed in 1984 with an annual mean rainfall of 170mm was still performing excellent (after 17 years in service) without any sign of potholes or other surfacing defects.
Kalokol was completed in 1985 with a traffic loading of cumulative AADT and E 80 kN of 0.2 and 0.16 mill, respectively. Annual mean rainfall 170 mm. Base layer thickness of 70 mm with CBR soaked of 50. Aggregate (0-18 mm) for the double Otta Seal was natural occurring uncrushed quartz gravel with an ACV/LAA of 26/45. Being in service for 10 years with no maintenance the surfacing is performing extremely well, without any signs of surfacing defects.

Mombasa, Road trial at Kwale was constructed in early 1985. The trial consists of two different types of base material, laterite unstabilised and laterite stabilised with 6% coral fines. Aggregate for two types of surface treatments (double Otta Seal and conventional Chip seal) were used. For the Otta Seal natural occurring laterite (ACV/LAA 42/54 with 10% passing the 0.075mm sieve and where the oversize were screened out and crushed), and coral stone (ACV/LAA 32/38 with 4% passing the 0.075mm sieve). Fairly hard crushed sand stone aggregate (ACV/LAA of 22/36) where used for the Chip seal.

The bitumen used for the Otta Seal was cut back on site to form a MC 3000 viscosity grade using diesel and kerosine from an 80/100 pen. grade. For the Chip seal 80/100 bitumen was used. Application rates 1.8 - 1.9 l/m² for both layers of the Otta Seal and 1.7 and 1.3 l/m² for the Chip seal, first and second layer, respectively. After 10 years in service and with a traffic loading of cumulative AADT/E 80 kN of 0.87 mill. and 0.14 mill. respectively, and an annual mean rainfall of 820 mm all the sections performed excellently. It was however noticed that the Otta Seal had a dense waterproof surface texture, while the Chip seal had a more open texture and looked hungry for bitumen.

Road C106 was constructed in 1985 and has had the same traffic loading and rainfall as the previous section. Aggregate for a double Otta Seal was a mixture of both uncrushed and crushed coral stone as aggregate. After 10 years in service the appearance of the surfacing looks more like an A/C with a very dense waterproof matrix. A slight “fatty up” was noticed in the wheel paths.

In conclusion, the Otta seals in Kenya that has been in service between 10 and 17 years, and under different climatic and traffic conditions, has proved that uncrushed quartz and laterite gravel as well as uncrushed/crushed coral stone aggregate of inferior aggregate strength can be successfully used in an Otta Seal, provided appropriate binder type and applications are used.

The Otta Seal concept is included in the Kenyan Road Design Manual of 1987.

4.2.5 Botswana

Since 1974/75 the Rural Roads Programme, under the responsibility of Roads Department and funded by the Norwegian Agency for Development Cooperation (NORAD) had been building gravel roads into the rural areas. However, in 1977 it became evident that in an arid and hot climate as prevailing in Botswana gravel roads became difficult to maintain. In 1978 the first 10 km of both single and double Otta Seals were constructed at the Oodi road (Overby 1982 and 1990). The aggregate used was uncrushed but screened (removal of oversize) decomposed granite with an ACV of 40. Binders used were MC3000 and MC800 at an application rate of about 1.5 and 2.0 l/m². Application of the binder was carried out by a bitumen distributor while the aggregate was applied by hand. The Otta Seals showed extremely satisfying early performance in which triggered off several other Rural Roads project utilising both lake gravel deposits consisting of silcrete, quartz and hard nodular calcrite mixed with a small amount of calcareous silt stone with an ACV of 33 (Overby 1990)
and crushed silcrete and sand stone. These single Otta Seals were always covered by a light spray of binder MC3000 at an application rate between 0,7 - 0,9 l/m², and covered with Kalahari sand which was easily available over most parts of the country. These Otta Seals using inferior aggregate have performed well for more than 15 years carrying 250-300 vehicles per day. Per today close to 1000 km of roads have been surfaced with a single Otta Seal with a Kalahari sand seal on top. This accounts for about 20% of the bituminised road networks.

Experience with the performance of the Otta Seals in Botswana indicates that for low traffic roads (AADT <100) the more “coarser area” of the grading curve should be adhered to. While for AADT > 100 a more dense grading is preferred.

In the Botswana Road Design Manual of 1994 the Otta seal concept is included as an alternative surfacing for Low Volume Roads AADT < 500. The life expectancies for a single Otta Seal is 7-8 years, single Otta seal with a Kalahari Sand seal on top 8-10 years, and a double Otta seal 12 - 14 years.

4.2.6 Zimbabwe

As a part of the Secondary and Feeder Road Development Programme (SFRDP) (Sida and Sweroad 1995) a number of test sections were constructed between 1990 and 1993 using the Otta Seal concept. Traffic levels varied from about 30 to nearly 300 vehicles per day and the rainfall from less than 300 to more than 1200 mm per year. Materials used were both crushed and uncrushed quartz/granite and where the fines < 2,0 mm were screened out. After 3-5 years in service the Otta Seals had performed in an excellent manner, although some cracks were evident in some of the sections, but their origin has not been determined conclusively.

4.2.7 Bangladesh

Through the Local Government Engineering Department (LGED) Otta Seals were in 1992 constructed as a part of the Environmental Trial Road at Faridpur (LGED 1994), that aimed at finding a more flexible and durable bituminous surfacing than currently used for Feeder Roads which consisted of a 25mm thick bituminous carpeting. Aggregate for the Otta Seal was screened river gravel 0-16mm (quartz and basalt) that was placed along the road side and applied immediately by hand after the binder was sprayed. The binder 80/100 pen. arrived in drums that was preheated and emptied into a tractor-pulled distributor. With the addition of cutters (paraffin) and flux (engine oil) the binder was improved to satisfy the short term (appropriate viscosity during construction) and the long term durability (softer bitumen over a longer period). The binder application rates varied between 1,9 - 2,1 l/m². Rolling was carried out by half-loaded trafficking trucks that followed a predetermined rolling scheme. Neither prime nor adhesion additives were used.

After 5 years in service the Otta Seals have performed well under a traffic loading between 50 - 80 commercial vehicles per day (mostly buses and trucks). As these feeder roads are built by labour intensive methods and designed on top of 4 - 5 m high embankments with a crane width of about 6,0 m, and for most of the year surrounded by water (sometimes flush with the surfacing) pavement movements are inevitable, hence a very flexible surfacing is required.

Per today about 15 km have been surfaced using labour intensive methods and the Otta Seal concept. A Sprayed Sealing Guideline for Otta Seals in Bangladesh has been prepared and its specifications form a part of the LGED Standard Specifications.
5.0 CONDITIONS THAT FAVOURE THE USE OF THE OTTA SEAL

The use of Otta Seal is favoured in particular by conditions where the following factors play an important role:

- Flexibility and durability of the surfacing are required to tolerate, for example, comparatively low quality, high risk for pavement movements and low bearing capacity with high deflections.
- Scarcity of available materials, and where maximum use is highly desirable.
- The workmanship is considered to be of indifferent quality, or where labour intensive input is warranted.
- The capability of future maintenance is questioned.
- A waterproof surfacing is required for a number of years without maintenance.
- Under environmental conditions with high solar radiation that increases the weathering of the binder.

Based on a global performance of the considerable length of Otta Seals being constructed during the last 30 years under quite variable environmental conditions, it appears that in appropriate circumstances this type of surfacing is undoubtedly cost-effective.

6.0 CONCLUSION

Since the time of its inception in the Otta valley in Norway, the Otta Seal method has had an extended use, from being an economical “maintenance seal” to a fully fledged bituminous surfacing with no other limitations regarding traffic than one would apply to any other sprayed bituminous surfacing. The Otta Seal concept is an example of the innovative use of local, often marginal quality materials, in combination with appropriate bituminous binders to produce durably surfacing under a variety of environmental conditions, ranging from cold-freezing climates to tropical hot/wet and desert dry and very hot.

The Otta Seal has proved to be a very cost-effective surfacing and its use has in many circumstances made allowances to construct roads under very unfavourable prevailing conditions, where conventional surfacing approaches would have been too expensive or not possible at all. It is therefore recommended when it comes to appropriate surfacing for roads (low volume roads) carrying traffic volumes of less than 1000 vpd to make cost comparisons to other sprayed bituminous surfacing, assessing the availability of local materials and their use in an Otta Seal. This exercise would in many cases derive to the conclusion that an Otta Seal would be the most economical and appropriate surfacing type.

Table 1: Relative Ad - and Disadvantage of the Otta Seal over Conventional Seals

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Otta Seal</th>
<th>Conventional Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of local materials</td>
<td>Relaxed aggregate requirements in terms of strength, grading shape, etc. Makes maximum use of crushed products or locally available natural gravels</td>
<td>Stringent aggregate requirements in terms of strength, grading, shape etc. Makes minimum use of crushed products</td>
</tr>
<tr>
<td>Design</td>
<td>Empirical approach to design. Relies to some extent on guideline and trial on site. Design may change during construction</td>
<td>Rational approach to design. Relies on confirmatory trial on site. Probably no change during construction</td>
</tr>
<tr>
<td>Construction</td>
<td>Not sensitive to standards of workmanship. Labour intensive methods can easily apply.</td>
<td>Very sensitive to standards of workmanship. Labour intensive methods difficult to apply.</td>
</tr>
<tr>
<td>Durability of seal</td>
<td>Very durable due to use of softer binders and denser interlock</td>
<td>Less durable due to use of harder binders</td>
</tr>
</tbody>
</table>

**Table 2: Qualitative Comparison of Otta Seal versus Conventional surface Treatment**

<table>
<thead>
<tr>
<th>Property</th>
<th>Otta Seal</th>
<th>Conv. Chip seal</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design method</td>
<td>Mostly Empirical</td>
<td>Semi-empirical/rational</td>
<td>Otta Seal relies more on experience and judgement during construction</td>
</tr>
<tr>
<td>Grading of aggregate</td>
<td>Wide, incorporating fines and some dust</td>
<td>Narrow and require dust free aggregate</td>
<td>20-40% of what normally would have been quarry waste is incorporated into the Otta aggregate. Production cost reduced ~ 40%</td>
</tr>
<tr>
<td>Binder type</td>
<td>Soft (low viscosity) 150/200 pen, MC 800/3000,</td>
<td>Hard - typically 80/100 pen</td>
<td>Soft binder is required with Otta Seal in order to coat all the particles</td>
</tr>
<tr>
<td>Aggregate type</td>
<td>Natural gravel or crushed stone</td>
<td>Crushed stone</td>
<td>Laterite, decomposed granite, lacustrine gravel deposits and coral stone have been used successfully</td>
</tr>
<tr>
<td>Aggregate strength</td>
<td>Strong to weak</td>
<td>Strong</td>
<td>ACV of 40 have performed well</td>
</tr>
<tr>
<td>Flakiness/shape</td>
<td>Very relaxed</td>
<td>Low tolerance</td>
<td></td>
</tr>
<tr>
<td>Adhesion</td>
<td>High tolerance</td>
<td>Low tolerance</td>
<td></td>
</tr>
<tr>
<td>Ease of construction</td>
<td>Very high</td>
<td>Very tight</td>
<td>Fatty spots may require re-spreading of finer material</td>
</tr>
<tr>
<td>Texture and Appearance</td>
<td>Smooth, rich with A/C appearance</td>
<td>Rough, lean</td>
<td></td>
</tr>
<tr>
<td>Typical initial cost ratio</td>
<td>1</td>
<td>1,2 - 1,4</td>
<td>Will varies depending on local conditions and hauling distances</td>
</tr>
<tr>
<td>Typical Service Life</td>
<td>Single 7-9, double 12-15 years</td>
<td>6 - 10 years</td>
<td>Traffic volumes less than 500 vpd</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Revj. spray not req.</td>
<td>Revj. after 2- 3 years</td>
<td>Less periodic maint. with Otta seal</td>
</tr>
</tbody>
</table>

7.0 REFERENCES

Overby. C. 1997. Personal communication with Swedish and Iceland Road Authorities.