OTTA SEALS: A SURFACING SOLUTION IN DEVELOPING REGIONS

Submission date: 12 November 2012
Word count: 5310 words; 5 Tables, 1 Figure

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ABSTRACT

The provision and sustainability of infrastructure in the developing world remains a huge challenge for road authorities, and funding and donor agencies. Gravel roads provide early life service, but later fail in their function because of inadequate maintenance. Traditional surfacings such as chip seals or asphalt require high quality materials and specialist expertise, which may not always be available in outlying areas. A cost effective solution to providing durable surfacings is the Otta seal. It consists of a soft binder and a graded aggregate, and can be constructed labour intensively with minimal equipment. The objective of the paper is to present a case for wider use of Otta seals in countries in transition to ensure a long-lasting transport legacy. Brief detail is provided on the design and construction of the Otta seal, and the extent of international use and performance. Confirmation of the technical capabilities leads to the evaluation of the socio-economic and institutional sustainability, which are critical issues in the implementation. On the basis of the review presented, it is concluded that the Otta seal is technically feasible and economically sustainable, and thus a suitable option for surfacing that needs to be seriously considered by road authorities and donor agencies.
INTRODUCTION
The provision and sustainability of infrastructure in the developing world remains a huge challenge for road authorities, and funding and donor agencies. The easiest way of providing access for farmers to markets, and the population at large to social services such as medical, financial and shopping, is gravel roads. Gravel roads provide early life service, but later invariably fail in their function because of inadequate maintenance. Funding agencies have insisted on and road authorities attempted the creation of a maintenance organization and capability to overcome these limitations. It has not always been successful as procurement of parts and repairs for maintenance equipment in outlying areas has been a challenge, with the result that equipment availability has been unacceptably low. Furthermore, substantial quantities of gravel, a non-renewable source, are lost annually and there is dust generation which could affect the health and safety of users and communities. The cost of regravelling is beyond the financial resources of many road authorities, and regravelling cycles of more than 20 years have been recorded [1]. This is thus not a sustainable option. Part of resolving the problem is to provide economical engineering solutions that are cost-effective over a life-cycle and that require minimal inputs of scarce management resources. Providing long-lasting bituminous surfacings is a potential technology. It also has benefits in that the day-to-day maintenance requirements are reduced leading to lesser management inputs.

Traditional surfacings such as chip seals or asphalt require high quality materials, specialist expertise and require specific equipment and plant, all of which may not always be available in outlying areas or on islands such as in the Pacific. A cost effective solution to providing durable surfacings is the Otta seal. It consists of a soft binder and a graded aggregate, and can be constructed labour intensively with minimal equipment. The objective of the paper is to present a case for wider use of Otta seals by road authorities, and funding and donor agencies to ensure a long-lasting transport legacy. Brief detail is provided on the design and construction of the Otta seal and the extent of international use and performance. Confirmation of the technical capabilities leads to the evaluation of the socio-economic and institutional sustainability, which are critical issues for the implementation in countries in transition.

REVIEW OF THE DESIGN OF OTTA SEALS
Traditional thin surfacings generally comprise the following: (asphalt is not considered as it is not used on low-volume roads):
- Single or double chip seals;
- Cape seals;
- Slurry seals; or
- Sand seals have been used effectively in many environments.

These surfacings, shown schematically in Figure 1, have provided good service, but their design and construction requirements are stringent. If these requirements are not met, severe problems are encountered, as is discussed below:

For chip seals high quality single sized aggregate with a 10% FACT strength of preferably greater than 210 kN is required. If weak aggregates, say with a strength of 100 kN, are used there is rapid break-down of the aggregate and severe stone loss results, leading to premature potholing.

The correct binder application rate of chip seals is critical. Too much binder results in severe flushing (bleeding) which is a safety hazard. Too little binder will result in severe stone loss, and then potholes. The expertise of the design and construction team is thus paramount.

The same conditions as above apply to Cape seals, but in addition two different processes are used which complicates the construction process.

A slurry seal is a thin skin, and has not been found to be durable as new construction directly on a base. It is thus not a sustainable option.

Sand seals have been used effectively in many developing regions, but their popularity has waned in the recent past as high quality coarse sand is required and this is difficult to find. A suitable alternative to the above-mentioned surfacings is the Otta seal. It was developed in the Otta Valley in Norway, and consists of a graded aggregate and a soft binder. The design of the Otta seal is relatively simple. It relies on an empirical approach that is based on experience in the selection of both an appropriate type of binder and an aggregate application rate. Guidelines are available to guide practitioners in the design of Otta seals [2, 3].

By virtue of the differences compared with traditional surfacings, Otta seals offer the following advantages [3]:
- The ability to use inferior quality aggregate such as screened gravel rather than crushed rock without impairing the performance;
- The dense matrix is able to combat high solar radiation that causes rapid aging and hardening of the binder, and thus provides enhanced durability;
- Scope for using labour-based methods in many parts of the construction; and
The binder application rate is not as critical as for chip seals, as the aggregate is replaced until the binder accepts no more aggregate.

**FIGURE 1** Schematic illustration of various types of bituminous surfacing [2,3].

A single Otta seal with sand cover is a cost-effective solution for roads carrying less than 500 vpd. The double Otta seal is the most durable, but also the most expensive, and is only recommended for main roads carrying high traffic volumes (>500 vpd). Sometimes a sand layer is placed on a single Otta seal as a blinding layer. The benefits of using a sand cover seal are as follows:

- Improved stone retention in the underlying seal;
- Enhanced durability due to increased binder thickness and the forming of a dense surface texture;
- Protection of the aggregate in the underlying seal in the case of marginal quality of materials; and
- Reduced risk of damage in the case of imperfections in the underlying seal.

**Preferred aggregate properties**

Three aggregate grading envelopes are suitable for Otta seals. These are termed “Open”, “Medium” and “Dense”. They are numerically given in Table 1. Note that the preferred grading envelopes are “Medium” and “Dense”, where the “Dense” grading is typically used on roads carrying more than 1000 vpd, “Open” grading on roads carrying less than 100 vpd and the “Medium” grading for the intermediate traffic range. The preferred maximum size of aggregate is 16 mm, although 19 mm material can be used in a double seal. On the “Dense” grading the percentage of fines (passing the 0.075 mm sieve) should be limited to 10%, although with care fine material with 20% of fines has worked [3].

**TABLE 1. Otta seal grading envelopes [2, 3]**

<table>
<thead>
<tr>
<th>Sieve sizes (mm)</th>
<th>Open grading (% passing)</th>
<th>Medium grading (% passing)</th>
<th>Dense grading (% passing)</th>
<th>Test Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>RTA T201</td>
</tr>
<tr>
<td>16</td>
<td>80 – 100</td>
<td>84 – 100</td>
<td>93 – 100</td>
<td>AASHTO T 146-49</td>
</tr>
<tr>
<td>13.2</td>
<td>52 – 82</td>
<td>68 – 94</td>
<td>84 – 100</td>
<td>BS 1377</td>
</tr>
<tr>
<td>9.5</td>
<td>36 – 58</td>
<td>44 – 73</td>
<td>70 – 98</td>
<td></td>
</tr>
<tr>
<td>6.7</td>
<td>20 – 40</td>
<td>29 – 54</td>
<td>54 – 80</td>
<td></td>
</tr>
<tr>
<td>4.75</td>
<td>10 – 30</td>
<td>19 – 42</td>
<td>44 – 70</td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>0 – 8</td>
<td>3 – 18</td>
<td>20 – 48</td>
<td></td>
</tr>
<tr>
<td>1.18</td>
<td>0 – 5</td>
<td>1 – 14</td>
<td>15 – 38</td>
<td></td>
</tr>
<tr>
<td>0.425</td>
<td>0 – 2</td>
<td>0 – 6</td>
<td>7 – 25</td>
<td></td>
</tr>
<tr>
<td>0.075</td>
<td>0 – 1</td>
<td>0 – 2</td>
<td>3 – 10</td>
<td></td>
</tr>
</tbody>
</table>

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Paper revised from original submittal.
Material for the **sand cover seal** used in Otta seals can be crusher dust, river sand or fine pit sand which is free from organic matter and lumps of clay, and should be non-plastic. All the material should pass the 6.7 mm sieve.

There is a general requirement that the weighted **Flakiness Index** on the 9.5 to 13.2 mm, 6.7 to 9.5 mm and 4.75 to 6.7 mm fractions should not be more than 30%. This requirement is normally readily met by natural gravel sources. The **aggregate strength** requirements in terms of the 10% Fines Aggregate Crushing value (10%FACT) from the international literature are given in Table 2 [2, 3].

### TABLE 2.  Otta seal aggregate strength requirements [2, 3]

<table>
<thead>
<tr>
<th>Aggregate strength requirements</th>
<th>Vehicles per day at the time of construction</th>
<th>BS Test designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. Dry 10% FACT</td>
<td>&lt;100 kN</td>
<td>BS812</td>
</tr>
<tr>
<td>Min. Wet/Dry strength ratio</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;=100 kN</td>
<td></td>
</tr>
</tbody>
</table>

There is a general requirement that the weighted Flakiness Index on the 9.5 to 13.2 mm, 6.7 to 9.5 mm and 4.75 to 6.7 mm fractions should not be more than 30%. This requirement is normally readily met by natural gravel sources. The **aggregate strength** requirements in terms of the 10% Fines Aggregate Crushing value (10%FACT) from the international literature are given in Table 2 [2, 3].

**Binder selection and application rates**

Table 3 shows the recommended type of binder for Otta seals made with the respective aggregate gradings. Where “weak” aggregates containing a fairly high proportion of fines are used the appropriate binder will be MC3000 (viscosity of 3000 centistokes and a medium curing cutter). An MC3000 binder is produced on site by blending 92 to 95% of 150/200 pen bitumen with 8 to 5% of power paraffin (kerosene). Circulation in the tank is carried out for at least 1 hour after blending to ensure homogeneity, and special care must be taken as the operation could be hazardous. The benefit of using cutback bitumen is that the binder viscosity can be adjusted for the prevailing temperature regime at the time of construction. Since the Otta seal technology is for low-volume roads, a provisional upper Annual Average Daily Traffic (AADT) limit of 2000 vpd is recommended.

**TABLE 3.  Choice of binder in relation to aggregate grading and traffic in tropical climate [2]**

<table>
<thead>
<tr>
<th>AADT at time of construction (sum both directions)</th>
<th>Open grading</th>
<th>Medium grading</th>
<th>Dense grading</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than 1000</td>
<td>Not applicable</td>
<td>150/200 pen grade</td>
<td>MC3000 (AMC6)</td>
</tr>
<tr>
<td>100 to 1000</td>
<td>150/200 pen grade</td>
<td>150/200 pen grade</td>
<td>MC3000 (AMC6)</td>
</tr>
<tr>
<td>Less than 1000</td>
<td>150/200 pen grade</td>
<td>MC3000 (AMC6)</td>
<td>MC3000 (AMC5)</td>
</tr>
</tbody>
</table>

The required binder spray rates for Otta seals vary according to the following parameters:

- Traffic (AADT);
- Aggregate grading (open / medium / dense);
- The absorptivity of the aggregate particles; and
- Whether the base course in new construction is primed or not.

Hot spray rates lower than 1.5 l/m² should not be used, as this will not result in a durable surfacing. On steep gradients (>4%) binder application rates should be reduced by up to 0.3 l/m², as in the case of chip seals.

For aggregates with water absorption of more than 2%, the hot spray rate should be increased by 0.3 l/m² to cater for the absorption. In the case where the base in new construction has been primed the hot spray rate should be decreased by 0.2 l/m² for the first layer.

Table 4 gives the nominal hot spray rates for Otta Seals. No correction of bitumen spray rates should be made in the design to compensate for the solvent used in cutback bitumen. Depending on the adhesion characteristics of the aggregate, an adhesion agent is sometimes used.

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TABLE 4. Hot bitumen spray rates for un-primed base course or reseal (l/m²) [2]

<table>
<thead>
<tr>
<th>Type of Otta seal</th>
<th>Grading</th>
<th>1st spray</th>
<th>2nd spray</th>
<th>1st spray</th>
<th>2nd spray</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open</td>
<td>Medium</td>
<td>Dense AADT&lt;100</td>
<td>Dense AADT&gt;100</td>
<td></td>
</tr>
<tr>
<td>Double</td>
<td>1.6</td>
<td>1.7</td>
<td>1.8</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Single, with sand seal</td>
<td>0.9</td>
<td>0.8</td>
<td>n/a</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Maintenance reseal (single)</td>
<td>1.5</td>
<td>1.6</td>
<td>1.8</td>
<td>1.7</td>
<td></td>
</tr>
</tbody>
</table>

* On a primed base on new construction, the first spray rate is reduced by 0.2 l/m²

Aggregate application rates

It is important to apply sufficient amounts of aggregate to ensure that there is some surplus material during rolling and through the initial curing period of the seal. This aggregate embedment will normally take about 2-4 weeks to be achieved where crushed aggregate is used, after which any excess aggregate can be swept off. Where natural gravel is used the initial curing period will be considerably longer. The aggregate application rates should fall within the ranges given in Table 5.

TABLE 5. Aggregate application rates [2]

<table>
<thead>
<tr>
<th>Type of seal</th>
<th>Aggregate spread rates (m³/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open grading</td>
</tr>
<tr>
<td>Otta seals</td>
<td>0.013 to 0.016</td>
</tr>
<tr>
<td>Sand cover seals</td>
<td>0.010 to 0.012</td>
</tr>
</tbody>
</table>

Full details of the design of Otta seals may be found in generally accepted guidelines [2, 4 and 5].

CONSTRUCTION OF OTTA SEALS

The process of construction of Otta seals is similar to that of a conventional chip seal. The binder is sprayed onto the surface followed by the spreading and rolling of the aggregate. It is accepted that a proper pavement design has been conducted for new construction, and the required pavement layers to protect the in-situ materials have been provided.

Preparation of the base course or previous surfacing for reseal

A good bond between the base or previous surface and the new surfacing is as important for Otta seals as for any other bituminous seal. In the case of new construction the base course has to be cleaned so that there is no loose material or dust. A prime is not essential for Otta seals. Before spraying the binder, a light spray of water is applied to the surface to break the surface tension and prevent dust balling as is standard practice when spraying directly on the base course.

Before resealing the drainage has to be repaired or installed so that water does not pond next to the road. In the case of a reseal surface preparation is essential. All potholes have to be repaired, preferably six weeks before the Otta seal is placed. Cracks do not have to be sealed, as the thick binder layer is effective for crack sealing. Surface defects such as delamination or stone loss need to be repaired at least six weeks before placing the seal. A uniform surface appearance before sealing is essential for good performance, and this may be achieved by applying a slurry seal by hand over the damaged areas or porous old patches at least six weeks before sealing. The Otta seal is well suited for roads that are extensively cracked and patched provided they are still structurally sound with no extensive crocodile cracking or rutting.

Preparation for the sealing operation

The binder distributor has to be in good mechanical working order. There are several basic checks that need to be performed before spraying can start. These are:

- No leakages of oil or binder.
- The hood over the spray bar must be intact to prevent wind from blowing away the spray.
- The thermometer on the distributor must be checked against an external thermometer.
- The distributor must have a spray chart developed for the specific distributor, which shows the application rate as a function of speed.
• The fifth wheel must be checked during a dry run. The distributor is run at a constant speed over a fixed distance, and the speed checked by taking the time with a stopwatch.
• The distributor must have a dipstick which was calibrated for the specific distributor.
• The height of the nozzles above the road surface must be checked to ensure complete coverage. The height is such that double or triple overlap occurs. This must also be checked when the distributor is almost empty, to ensure that there are no changes with load.

In preparing the cutback bitumen the operation is hazardous, and no open flame (including cigarettes or heaters in bitumen tanks) must be permitted within 100 m. The cutter should not be mixed with bitumen having a higher temperature than 140°C. This is due to the hazards of flammable gas emission from the tank. The correct procedure is to pre-heat the bitumen to 140°C and either pump the cold cutter into the bottom of the tank through the designed hose and valve, or to pump the hot bitumen over in a new, cold tank already containing the cutter.

The following precautions should be strictly adhered to prevent the risk of fire or explosion:
• The cutter must NEVER be added through the manhole.
• Cutter should NEVER be pumped into an empty tank that is still hot after having contained bitumen.
• The bitumen level in the tank should NEVER be allowed to fall below that specified by the manufacturer while the heaters are in operation. This is normally a minimum of 150 mm above the highest point of the heater pipes.

After combining bitumen with cutter the mixture is immediately circulated for 1 hour in order to ensure a homogenous product. Sealing operations should, however, be curtailed if the road surface is moist or when rainfall is imminent.

**Actual construction of the Otta seal using construction plant**

Transverse joints should be constructed by normal good sealing techniques whereby at the start and end finishing sheets of thick paper are used. These sheets must be in position before spraying is permitted.

All the equipment and materials must be in position before spraying is permitted. The distributor must be tested outside the road to ensure that all nozzles are functioning. The distributor is then positioned, and a dipstick reading is taken. Sufficient aggregate must be in the trucks, and the chip-spreader must be in position.

Two pneumatic tyred rollers of at least 12 ton capacity are required, and they must also be in position to immediately start with the compaction. Visually the process is successful when the binder is being pressed up in-between the aggregate particles.

The key to a successful seal is adequate rolling. At least 15 passes with a pneumatic tyred roller over the entire area is required for adequate compaction. This means that every point on the road will have received at least 15 compaction applications. After completing the compaction with the pneumatic tyred rollers, a single pass with a 10 to 12 ton static tandem steel drum roller is applied to improve the embedment of the larger aggregate. Note that the aggregate will crush unnecessarily if more passes are applied.

Traffic is permitted on the new seal as soon as compaction is complete. The traffic will further assist with compaction of the Otta seal. A speed limit of 40 km/h must be enforced to prevent flying stone or unnecessary dust, and this speed limit should be enforced for 2 to 3 weeks or until the seal no longer accepts aggregate and the surplus aggregate is then swept off the road.

Special care is needed at longitudinal and transverse joints, as these are invariably the weakest points on the road. To avoid longitudinal joints it is preferable to spray the full width of the road in one pass. If the road is constructed as two lanes, then there should be minimum overlap of the bitumen spray of 150 mm. The aggregate should be broomed back to avoid the extra thickness, and additional heavy rolling is applied to even out the joints and to prevent a ridge which may be a hazard to traffic.

**Actual construction of the Otta seal using labour intensive construction**

The same principles and care as construction using a distributor, chip spreader and pneumatic tyred roller apply to labour intensive means. The binder may be applied by hand-spray equipment. Care must be taken as the hot binder is hazardous. It is easy to overheat the binder, which causes permanent damage, and temperatures must be carefully controlled. To ensure uniformity of application an area of 10 sq m will be marked out, and the required quantity of binder sprayed, before moving to the next area.

To assist with the spreading of the aggregate small heaps of material are placed on the shoulder in preparation to sealing. Labourers with shovels then spread the aggregate as soon as the 10 sq m area has been sprayed.

A pneumatic tyred roller is preferred for compaction, but in the absence of a roller a laden truck may be used, ensuring that all areas are covered by the wheels. Normal traffic compaction will also assist. Continual brooming to place the aggregate on the binder will be required, and construction speed limits must be enforced.
It is preferable to use a binder distributor to spray the binder uniformly, but labour can be used to spread the aggregate, as described above. If large areas are constructed a pneumatic tyred roller is preferred to ensure proper and uniform embedment.

**Post-construction care**

During the first two days after sealing, extensive rolling by pneumatic rollers are required to ensure that all particles embedded in the binder are properly coated. A minimum of 15 passes with the pneumatic tyred roller are applied daily during the hottest part of the day, covering the entire surfaced area. This activity will be performed in conjunction with brooming by labourers to restore the loose aggregate to the road. During this time any construction defects will also be corrected by hand.

After the brooming and rolling during the first two days after construction, the loose material must be broomed back onto the road every second day. After 2 to 3 weeks when there is no longer any sign of bleeding, and the surfacing no longer accepts aggregate, the balance of the aggregate is then swept off the road.

**Subsequent layers**

A minimum period of 8 - 12 weeks should elapse between the construction of the first and the second layers. This is to allow as much traffic as possible to traverse the surfacing as well as to allow evaporation of the solvent. During this period, the surfacing becomes more settled and in the wheel paths, and where the aggregate has become embedded by traffic, a “premix” like appearance should start to appear.

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

**INTERNATIONAL USE AND PERFORMANCE**

Since 1999, when it was reported [2] that Otta seals had been used in nine countries with varying climatic and environmental conditions, recent reports in the literature have shown that the popularity is increasing and use is more widespread. By 1999 the countries that had built Otta seals were three Nordic countries (Norway, Sweden and Iceland), four African countries (Kenya, Botswana, Zimbabwe and South Africa), Bangladesh and Australia. Recent reports in the literature have shown that use is growing, with Otta seals having been built in Ghana [6], Minnesota in the United States [7], New Zealand [8] and Nepal [9]. Trials have also been built in Namibia, Tanzania and Chile [3]. Pacific islands are introducing Otta seals as part of a World Bank funded project. This widespread use shows that the popularity is increasing under a range of environments. The growth in use is an indication of technical acceptance and economic viability.

The performance of the reported Otta seals is generally good. The life of a single Otta seal with sand seal is typically between 8 and 10 years, and a double Otta seal is 10 to 12 years [3]. In Norway roads with Otta seals older than 20 years have been reported [3]. These lives can be compared with single seal lives of 6 to 8 years, and Cape Seal (19 mm plus slurry) lives of 10 to 14 years [3].

Obviously most of the published reports provide positive feedback regarding performance. The presentation on the work in Ghana [6] showed marked differences in appearance and performance as a result of adequate rolling and limited rolling. This emphasizes the importance of proper compaction. Inadequate compaction also leaves a surfacing with variable texture, and areas of bleeding, which to the uninitiated [9] suggests an inadequate surfacing. This reinforces the need to broom loose material back onto the road until no further aggregate is absorbed by the binder.

Poor performance of Otta seals was reported in South Africa [10]. This was as a result of both the crushed stone and natural gravel materials being finer than the desired envelope. Fine material requires more binder because of the specific surface area, and the result is a thin layer with a very smooth texture (dangerous when the road is wet) and potential for adhesion to the tyres when road surface temperatures are high.

Furthermore, the aggregate contained oversize material (>16 mm) which was plucked out of the road by passing vehicles creating a hazard of broken windscreens. The holes left in the surfacing quickly deteriorated to form potholes, further affecting the performance. The international guidelines that have been developed form a sound basis for application and material selection, as non-observance of the guidelines results in poor performance.

In Nepal selective surfacing of unpaved roads took place at safety black spots (such as sharp curves) or where unwarranted erosion caused significant hazards. The construction process, which is mainly labour intensive, allows this type of treatment which would be more complicated if conventional construction procedures were followed. On steep gradient the shoulders up to the drain were also sealed as an erosion control measure, which would not have been readily possible with other types of surfacing.

The widespread reports of positive and successful performance, despite limited reports to the contrary, show that Otta seals are technically feasible.
CONSIDERATIONS OF IMPORTANCE FOR IMPLEMENTATION

Besides the technical excellence of a technology, road authorities, and funding or donor agencies also consider its socio-economic and institutional viability and sustainability. These issues are discussed next in terms of the use of Otta seals.

Economic viability
The economic viability depends on the cost regime in a particular environment. A favourable life-cycle benefit-cost ratio of more than twice of that of conventional seals [3], for a particular situation, was found. This advantage is derived largely as a result of the following factors:

- lower initial construction cost due largely to greater utilisation of the crushed aggregate or screened gravel (typically 20% less than for a conventional double chip seal);
- use of screened natural gravel rather than crushed aggregate;
- marginally longer service life (typically 10-12 years for a single Otta seal with a crusher dust or river sand seal versus 6-10 years for a double chip seal);
- lower maintenance costs (omission of prime and fog spray; longer resal and road marking cycles).

From an institutional perspective, a surfacing life of 6 years means that every year one-sixth (16%) of the roads with that surfacing have to be ressealed. However, only one-twelfth (8%) of the roads have to be ressealed if the surfacing life is 12 years. This is a significant reduction in management effort and cost, often ignored in economic analyses. This is also the type of institutional actions that road authorities strive for and funding or donor agencies support.

The lower per unit cost (about 20%) of an Otta seal means that a longer length of road can be treated compared with traditional surfacings such as a chip seal for a given budget. Alternatively, a smaller budget is required to treat a given length of road.

Labour based construction
Otta seals and sand seals are ideally suited for construction by hand [3], unlike the other surfacing types. Activities which can be performed are [3]:

- digging and screening aggregate by hand – flat screens or rotary screens can be used;
- loading screened aggregate for transport to site;
- spreading screened aggregate directly on the sprayed bitumen;
- off-loading screened aggregate onto heaps placed along the road;
- spreading screened aggregate from heaps placed along the road onto the sprayed bitumen;
- removing oversize aggregate from the surfacing;
- pulling the drag broom in order to improve the distribution of aggregate;
- brooming back dislodged aggregate into the exposed areas during initial placement, and for at least a further 14 days;
- brooming off all excess aggregate.

Producing crushed aggregate by hand does not result in a satisfactory product, as hand-broken aggregates are invariably too flakey to meet the requirements. In many developing environments labour is also familiar with the construction process, as it is similar to the construction of sand seals, and this is a technology which is has been universally used. Sand seals suffer from a disadvantage that suitable coarse sand is difficult and costly to obtain.

Socio-economic impact
Employment creation is one of the major benefits of the construction of Otta seals by labour based methods in developing economies. Poverty reduction and regional economic growth are two results of such a programme, and highly desirable in developing countries. The direct project-related benefits that enhance the sustainability of the Otta seal include the following [3]:

- Job creation in rural areas where other means of formal employment are either very limited or, in many cases, simply not available;
- Community involvement and a sense of ownership of the infrastructure engendering a greater likelihood of their participation in the subsequent maintenance of the roads;
- Elimination of gender bias by providing opportunities for women to increase their contribution to the economy;
- Injection of money into the local economy leading to economic empowerment and poverty alleviation, especially for rural communities (35% of the contract value is paid as wages compared with 15% on an equipment based surfacing construction project);
Development of local skills which can serve as a springboard for small-scale local contracting industry with follow-up opportunities for road maintenance and a related contribution to sustainable rural livelihoods.

Otta seals are relatively easy to construct, after proper training, and thus lend themselves to SMME (small, medium and micro-enterprises) engagement. Local expertise can be used to establish SMME contracting companies, which engender entrepreneurship and employment creation. In some regions the establishment of a local contracting industry is one of the economic development goals.

Environmental sustainability

The provision of dust-free roads has major benefits to health (reduced lung ailments), improvement in traffic safety (better visibility) and reduced pollution of crops and animal fodder adjacent to roads. The reduced use of scarce, non-renewable gravel for regravelling programmes is a major benefit. Initially gravel resources may be relatively cheap and plentiful, but over time these bountiful resources are used up. The result is that sources further afield need to be found. In South Africa in some areas gravel has to be transported over distances as far as 100 km. The currently cheap gravel should be valued at a future price which could include longhaul distances or commercial production by crushing. Economists use a shadow price, and this is encouraged.

Although sealing of gravel roads is one way of reducing pollution and improving the quality of life, it must be appreciated that uncontrolled sealing of gravel roads could lead to an unmitigated disaster. The reason for this is that the material properties of a base layer in a sealed road are different from the properties of a gravel wearing course. Crucial properties are the plasticity index, percentage passing the 0.075 mm sieve and the CBR. If these values do not fulfill the national standards then a road that is sealed would become unstable (moisture is trapped under the surfacing as a result of the diurnal temperature cycle) and result in cracks in the surfacing, which, with rainfall would pothole. Such a road then requires large-scale maintenance, and premature reconstruction. The use of Otta seals, or for that matter any bituminous seal, should not ignore standards and good engineering. Furthermore, unpaved roads that are upgraded should not attract unwarranted traffic for which the road is not designed.

CONCLUSIONS AND RECOMMENDATIONS

The objective of the paper was to present a case for wider use of Otta seals by road authorities in economies in transition, and funding and donor agencies to ensure a long-lasting transport legacy. It was concluded that:

- Otta seals are technically viable and suitable in developing environments.
- Otta seals are economically feasible in a life-cycle analysis by virtue of their lower initial cost compared with traditional surfacings and longer life.
- The use of labour in the construction process is not an after-thought, but an integral part of the construction process to achieve a quality product.
- Employment of labour in the construction of Otta seals creates jobs and alleviates poverty.
- Construction of Otta seals is ideally suited for creating a local construction industry through small, medium and micro-enterprises (SMME).
- Otta seals provide environmental sustainability in that dust, a health and safety hazard, is reduced when used as surfacing treatment on unsealed roads.
- Otta seals are useful both as a resurfacing treatment to paved roads and also for upgrading a gravel road to a sealed surface.

These conclusions are paramount in the vision of road authorities in developing countries, and funding and donor agencies and it is thus recommended that Otta seals should be considered as a candidate for upgrading and maintenance programmes. Care should be taken to apply sound engineering in the structural design of pavements and the selection of construction materials on roads to be sealed. Otta Seals place a lower demand for heavy construction equipment, and labour based methods may act as a substitute for equipment in certain circumstances.

REFERENCES


