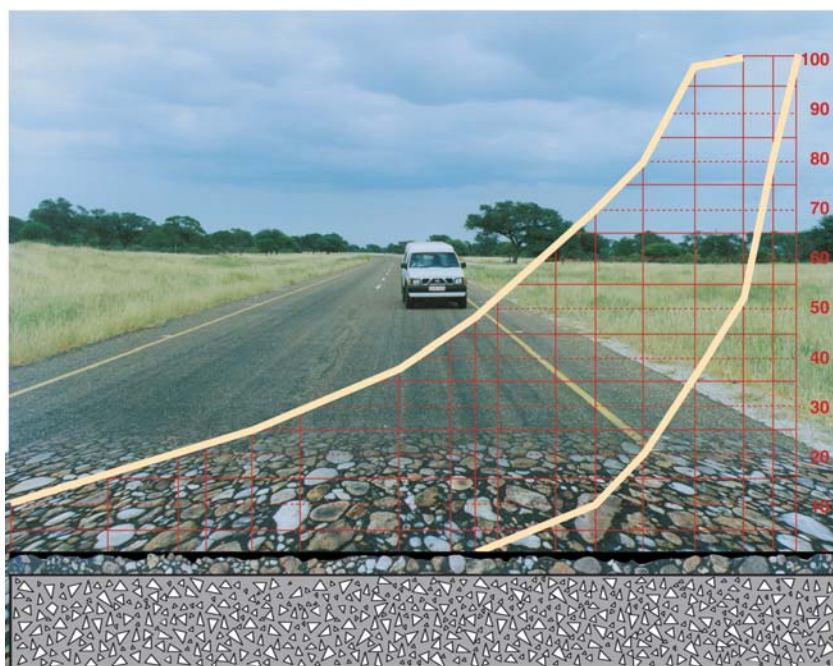


# A Guide to the Use of Otta Seals



Norwegian Public Roads  
Administration



**Publication no. 93**

*By Charles Øverby*

# **A Guide to the Use of Otta Seals**

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**Directorate of Public Roads**

Road Technology Department  
International Division

Oslo, August 1999

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# PREFACE

The first Otta Seal surfacing was constructed in Norway during the years 1963 - 1965 based on an innovative and experimental approach. The main objective was to develop a method that could effectively improve the quality of the gravel roads to a cost equal to the gravel road maintenance. In 1965 the Norwegian Road Research Laboratory had successfully developed a sprayed bituminous seal using graded gravel and soft binder at a relatively high binder content. During the next 20 years, more than 12000 km of unpaved roads were surfaced by the Otta Seal method, comprising about 20% of the total paved road network in Norway. The Otta Seal rapidly proved to be very cost-effective and durable, and its performance much better than originally expected.

During the next 25 years Norwegian engineers has been promoting this type of sprayed bituminous seal at various parts of the world, adopting appropriate specification, matching the local environment. The reported experiences have without doubt been very successful ranging from areas of freezing cold to hot/wet and dry/very hot climate. In many cases, strict adherence to the more conventional standards for bituminous surfacings would either prohibit the project or made it unnecessarily costly. However, the lack of information regarding the Otta Seal, properties, design (previously the design of Otta Seals was based on empirical methods, rather than the more rational methods used for Chip Seals), construction and performance and the reluctance from the construction industry to embrace new technology, has so far limited the use of this type of sprayed bituminous surfacing.

The two main objectives of this Publication is to provide the following:

- Provide a ready, practical reference for the engineers and technicians who design and execute the sprayed bituminous work.
- Summing up 25 years experiences with the global use of the Otta Seals providing technical evidence and economical justifications that the Otta Seals have no other limitations than other types of sprayed bituminous seals.

It is my sincerely hope that this Publication will provide the required confidence in using this type of innovative type of sprayed bituminous surfacing, as well as to be a guidance to the practitioners, governmental engineers and technicians, contractors and consultants in situations that will favour this type of sprayed bituminous surfacing.

Oslo, 10<sup>th</sup> of August 1999



Olav Sjøfteland

Director General of Public Roads

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The number of persons that contributed to that Guideline is also highly credited for their inputs to this Publication.

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# INTRODUCTION

## 1.1 Background

Budgetary constraints for the provision of sealed low volume roads both in the industrialised 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 maximise 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 non-standard 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 in road construction is with the judicious choice of bituminous surfacing. Normally, the selection of the most cost-effective surfacing would be based on a life cycle analysis of appropriate surfacing types in which the influence of a range of factors is investigated. One type of surfacing which has proven to be eminently cost-effective in appropriate situations is the Otta Seal using graded aggregate. For more than three decades has this type of bituminous surfacing proved to be very cost effective both in Scandinavia, Iceland, East and Southern Africa and partly also in Bangladesh.

## 1.2 The Guideline, purpose and scope

The main purpose of this Guideline is to provide practical guidance on the design, construction and maintenance of Otta Seals. The Guideline also summarises the experience that has been gained in the use of the Otta Seal for the last three decades in a global perspective. In so doing, the intention is to improve the understanding of this type of road surfacing and to promote its use under similar environments where optimum use has to be made from limited funds available for road construction and maintenance.

It is emphasised that this Guideline should be used for the purpose intended, i.e. as a guideline and not as a prescriptive approach or standardised way of designing, constructing or maintaining Otta Seals. Some judgement will always have to be exercised in arriving at decisions regarding the parameters that are incorporated in particular designs.

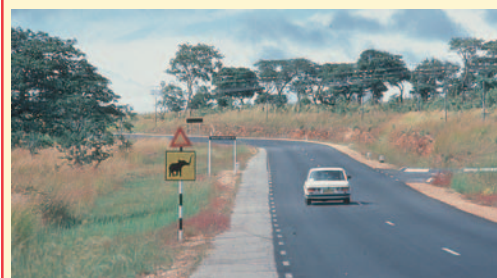
The Guideline is intended for use by the various organisations associated with the design, construction and maintenance of Otta Seals. These organisations include employers, consultants, contractors and materials suppliers.

## 1.3 Structure of the Guideline

The Guideline contains twelve main chapters, following the general introduction, which is given in this Chapter, Chapter 2 gives an overview of the role and function of bituminous surfacings. The origin and the innovated approach for the Otta Seal is given in Chapter 3. Chapter 4 provides details of the Otta Seal, description and performance characteristics. This is followed by the Chapters 5 and 6 which describe the materials constituents of the Otta Seal. Chapter 7 then outlines the various selection criteria affecting the



*Unsealed roads very often provide an unsatisfactory driving comfort and associated high maintenance and operational costs. Dust pollution is also a problem in urban areas. (South Africa).*

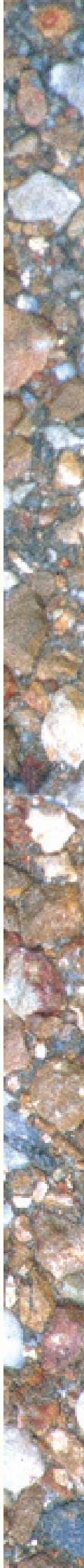


*A bituminous surfacing protects the base course layer and provides good riding quality. Hence, low operational costs. (Zimbabwe).*

# 1

choice of surfacing followed by the Chapters 8, 9 and 10 which deal with the design, construction and maintenance of Otta Seals respectively. The various contractual issues associated with the use of Otta Seals is described in Chapter 11. Finally, Chapter 12 describes the global use of the Otta Seals as case histories, followed by a historical summary.

Two Appendices are provided, Appendix A and B gives Mass/Volume conversion tables and Abbreviations, respectively.



# BITUMINOUS SURFACINGS

## 2.1 Role and function

Bituminous surfacings are an integral component of paved roads and perform a number of functions that offer many advantages over unsealed roads. These include:

- Provision of a durable, impervious surfacing which seals and protects the pavement layers from moisture ingress and consequent loss of pavement strength and degradation;
- Provision of a skid-resistant surface which can resist the abrasive and disruptive forces of traffic and the environment;
- Prevention of the formation of corrugations, dust and mud which generally permits relatively safe travel at higher speeds and lower vehicle operating and maintenance costs.

As for all bituminised roads, the pavement strength must be adequate to carry the anticipated traffic loading.

## 2.2 Surfacing types

Various types of bituminous surfacing have been and are used on the global Public Highway Network. These included:

- Sand Seals
- Surface Dressings (Chip Seal)
- Cape Seals
- Otta Seals
- Asphaltic Concrete (varying thickness)

The above seal types are illustrated in Figure 2.1.

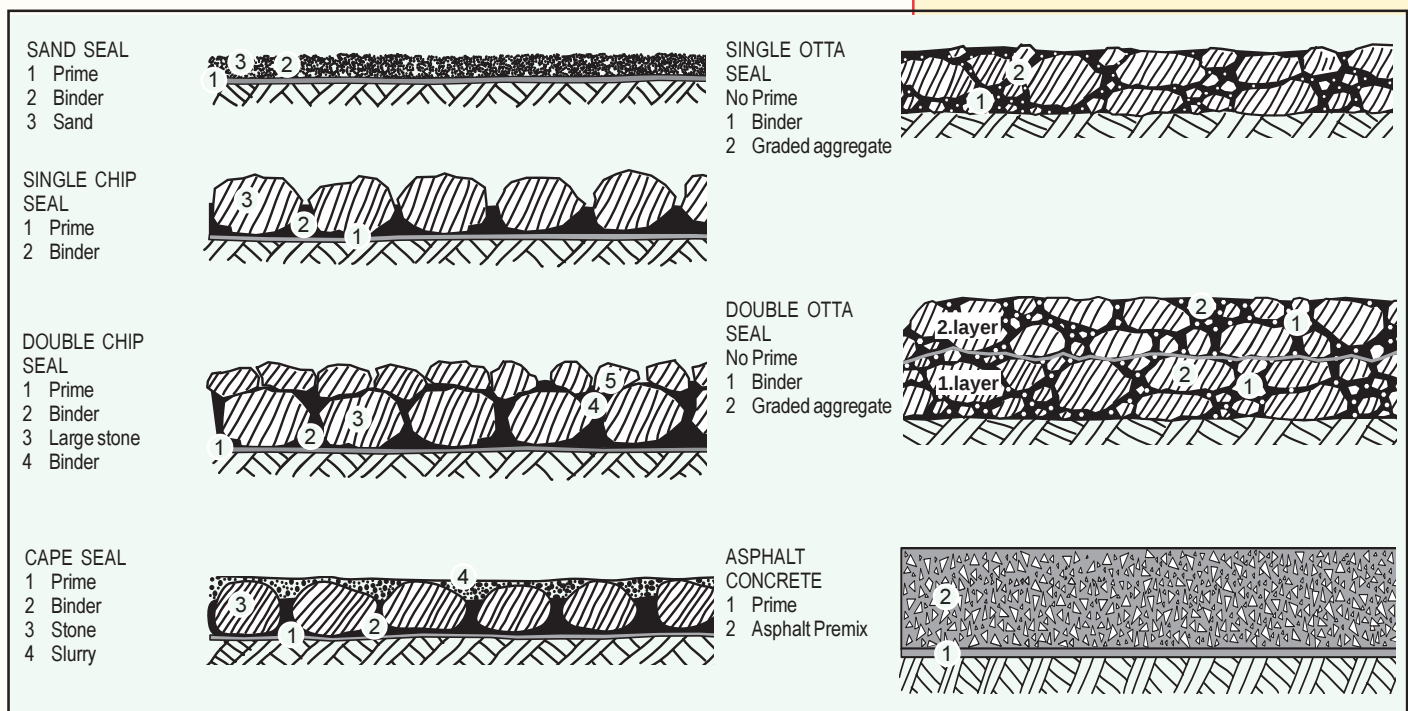


Figure 2.1 Schematic illustration of various types of bituminous surfacings.

## 2.3 Factors affecting choice

The choice of bituminous surfacing in any given situation will depend on a number of factors which include the following:

- Type of pavement (strength, flexural properties, etc.);
- Economic and financial factors (funds available, life cycle costs, etc.);
- Riding quality required;
- Operational factors (traffic, surface stresses, geometry, etc.);
- Safety (surface texture, interference with traffic, etc.);
- Environmental considerations (climate, noise, etc.);
- Construction and maintenance strategies;
- Characteristics of available materials (aggregate, binder, etc).

Subject to the surfacing meeting various technical and environmental requirements, a life cycle cost comparison of alternative surfacing types should be carried out as a basis for determining the most cost-effective solution. Such a comparison would normally consider not only initial construction costs, but also maintenance and vehicle operating costs.



# ORIGIN OF OTTA SEALS

## 3.1 Background

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. 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. During the years 1963 - 65 trials were carried out in the Otta Valley where its name derives from.

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 type is today considered to have no other limitations regarding traffic volumes than one would apply to any sprayed bituminous surfacing.



*The unpaved road network was in a poor condition in Norway in the early sixties. During the thaw period often un-passable for both light and heavy vehicles. (Norway).*



*The Otta Seal originates from the Otta Vally in Norway where it was first used. (Norway).*

The lack of information regarding the Otta Seal, properties, design, construction and performance and the reluctance of the construction industry to embrace new technology has so far limited the use of this type of bituminous surfacing.

## PERFORMANCE CHARACTERISTICS

### 4.1 Description and types

Otta Seals consist essentially of a 16 - 32 mm thick bituminous surfacing constituted of an admixture of graded aggregates ranging from natural gravel to crushed rock in combination with relatively soft (low viscosity) binders, with or without a sand seal cover. This type of surfacing contrasts with the single sized crushed aggregate and relatively hard (high viscosity) binders used in conventional surface dressings e.g. Chip Seals.

There are various types of Otta Seals in terms of number of layers, type of aggregate grading and whether or not a cover sand seal is used. These various types may, in general, be summarised as follows:

1. *Single Otta Seal*  
aggregate grading “open”, “medium” or “dense”
  - with sand cover seal
  - without sand cover seal
2. *Double Otta Seal*  
aggregate grading “open”, “medium” or “dense”
  - with sand cover seal
  - without sand cover seal

All types single surfacing seals demand very high standards of workmanship to perform well and therefore carry higher risks of performing unsatisfactorily.

The choice of type of Otta Seal is dependent on a number of factors which are described in Chapter 7.

### 4.2 Mechanism of performance

The mechanism of performance of Otta Seals is quite different to that of the more conventional Chip Seals. These differences may be summarised as follows:

**Otta Seal:** Graded aggregate is placed on a relatively thick film of comparatively soft binder which, on rolling and trafficking, can work its way upwards through the aggregate interstices. In this manner, the graded aggregate relies both on mechanical interlocking and bitumen binding for its strength - “a bit like” a bituminous premix.

Trafficking of the seal immediately after rolling is desirable and its final appearance is formed after 4 - 8 weeks giving a “premix” like appearance in the wheel paths. Priming of the base is normally not required.

**Chip Seal:** In the case of the conventional Chip Seal surfacing, aggregate is placed on a film of comparatively hard binder with the objective of “gluing” the former to the latter. Thus, the Chip Seal relies very much on the bond between the binder and the aggregate for its strength. If this bond is insufficient (e.g. due to the use of a too thin binder film or the occurrence of in-service embrittlement due to binder oxidation) then ravelling will occur. Moreover, the selection of the respective aggregate sizes is critical to ensure interlocking between the first and second layers. Traffic on the surfacing needs to be carefully controlled until the binder is finally set. Priming of the base is normally required.



*The mechanical interlocking, and bitumen binding of the Otta Seal is “a bit like” bituminous premix. A Double Otta seal.*

The concept of bleeding should also be viewed quite differently between Otta Seals and the more conventional Chip Seals. In the former, if excess bitumen works its way to the surface during rolling or trafficking, it can simply be blinded with fine aggregate or coarse to fine sand. The fine aggregate (or sand) tends to be fairly readily coated by the comparatively soft binder and work its way into the interstices of the graded aggregate to produce a tight, closely knit surface which looks very much like a conventional premix. In contrast, bleeding of Chip Seals can be more problematic due to the difficulty of coating the fine blinding aggregate (or sand) with a relatively harder binder.

Due to the differences in the mechanism of performance between Otta Seals and Chip Seals, it is important to recognise that their respective methods of design and construction should not be assumed to be similar.

Figure 4.1 illustrates the difference in make-up and mechanism of performance of a Single Otta Seal in comparison to a Single Chip Seal.



Single Otta Seal (0-16 mm). Thickness: minimum 16 mm



Single Chip Seal (13,2 mm). Thickness = ALD (8 to 10 mm)

Figure 4.1 Mechanism of performance, a single Otta Seal compared to a single Chip Seal.

The dense, closed texture of Otta Seals generally promotes impermeability and protects the binder from direct solar radiation and associated oxidation and embrittlement.

If the procedure for design and construction of a Chip Seal is adopted for an Otta Seal, the result will be disastrous!

## 4.3 Performance characteristics

### General

The performance of Otta Seals depends (as for all other types of surfacing) on a number of factors such as:

- type of Otta Seal, (texture, durability etc.)
- bearing capacity of the pavement
- traffic using the road

### Durability - texture

The dense, closed texture of an Otta Seal, which is further enhanced with the use of a cover sand seal, is particularly advantages in the hot temperature conditions that occur in the country. In such conditions, high solar radiation significantly increases the rate of oxidation of the surfacing binder which occurs less quickly with Otta Seals as compared with the more conventional Chip Seals.



Close-up of the graded aggregate used in the Otta Seal. Note the dense matrix and interlocking.



Otta Seal with sand cover seal, where the dense matrix is further enhanced. (Botswana).

# 4

The influence of aggregate shape, strength and grading is of moderate importance due to the mechanism of behaviour of Otta Seals in contrast to the significance of these properties in conventional Chip Seals.

Visual evidence of the performance of Otta Seals under varying levels of traffic indicates that traffic volumes higher than 500 vpd are, in fact, advantageous to the performance of the seal.



*The possible use of natural occurring gravel, including the fines, are some of the factors that favour the use of Otta Seals. (Kenya).*



*A newly laid Otta Seal (with a high fines content) will for the first 2 - 4 weeks give dust pollution. (South Africa).*



*An Otta Seal will for the first few months after opening to traffic exhibit a rich bitumen appearance, which initially appears non-uniform and inferior compared to the conventional Chip Seal. (Botswana).*



*After some months in service the Otta Seal “beds down” and provide an uniform appearance. (Botswana).*

## Flexibility

Long service lives experienced in Norway and Kenya with Otta Seals placed on pavements with relatively high Benkelman Beam deflections (in excess of 1.25 mm) indicate that this type of seal exhibits excellent flexibility.

## Traffic

The Otta Seal concept is not considered to have any limitations regarding traffic volumes than would not also apply to any other type of sprayed bituminous surfacing.

## 4.4 Relative advantages and disadvantages

Otta Seals differ in many respects from conventional sprayed bituminous surfacings such as Chip Seals.

One of the major advantages offered by Otta Seals is their ability to perform well with aggregates of relatively low quality in terms of strength, shape, texture and dust content, giving rise to cost savings which can be considerable depending on project location, availability of aggregates and bitumen price. However, as with other types of bituminous surfacings, Otta Seals possess both advantages and disadvantages that are described below.

### Advantages

Some of the factors favouring the use of Otta Seals include situations were:

Road construction is taking place in remote areas where, for example, only natural gravels occur, and where it may be prohibitively expensive to set up crushing facilities;

- Workmanship may be of indifferent quality;
- Flexibility and durability of the surfacing are required to tolerate, for example, comparatively low quality, low bearing capacity pavements with high deflections;
- There is a low maintenance capability;
- High solar radiation levels prevail.

### Disadvantages

One of the main disadvantages of Otta Seals is their initial, inconsistent and somewhat patchy appearance during the first 4 - 6 months of their service life. During this stage, the surface may appear rich in bitumen or may even “bleed”, necessitating the spreading of sand or crusher dust over the affected area to absorb the excess of bitumen. This tends to give the erroneous impression to the lay person that something is wrong with the surfacing or that it is of inferior quality to the more traditional Chip Seal. However, this is certainly NOT the case. After some 8 - 12 weeks of trafficking the surfacing will start to “bed down” and will provide a more uniform and consistent appearance which looks somewhat like the more expensive Asphaltic Concrete that is generally used on very heavily trafficked roads.

Another disadvantage with the use of Otta Seals is with regard to the need to consider a number of additional contractual issues that need to be specially dealt with in the Contract Documents. These issues are discussed in Chapter 11.

Table 4.1 describes the relative differences between Otta Seals and conventional Chip Seals and indicates the qualitative differences between the two types of surfacing.

| Parameter                                   | Otta Seal                                                                                                                                                                                                                                                           | Conventional Chip Seal                                                                                                                                                                                                                                                                         |
|---------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Aggregate quality</b>                    | Relaxed requirements for: <ul style="list-style-type: none"> <li>- strength</li> <li>- grading</li> <li>- particle shape</li> <li>- binder adhesion</li> <li>- dust content</li> </ul> Maximises use of locally available natural gravel or of the crushed product. | Stringent requirements for: <ul style="list-style-type: none"> <li>- strength</li> <li>- grading</li> <li>- particle shape</li> <li>- binder adhesion</li> <li>- dust content</li> </ul> Maximised use of the crushed product is difficult, use of natural gravel is in practice inappropriate |
| <b>Binder</b>                               | Relatively soft binders (low viscosity) are required: 150/200 penetration grade or MC3000 or MC800 cutback bitumen.                                                                                                                                                 | Relatively hard binders are required for necessary stone retention: (80/100 pen. grade under hot conditions).                                                                                                                                                                                  |
| <b>Design</b>                               | Empirical approach to design. Relied earlier to a large extent on experience and site trials.                                                                                                                                                                       | Empirically based rational design methods.                                                                                                                                                                                                                                                     |
| <b>Construction technique</b>               | Relatively little sensitivity to standards of workmanship. Labour intensive methods easy to apply if desired.                                                                                                                                                       | Sensitive to standards of workmanship. Labour intensive methods difficult to apply.                                                                                                                                                                                                            |
| <b>Construction costs</b>                   | In most instances costs are lower than Chip Seals, up to 40% depending on the availability of aggregate.                                                                                                                                                            | Cost competitive only where good quarries are located nearby; the bitumen price is high and the traffic volumes are high (> 500 vpd).                                                                                                                                                          |
| <b>Contractual matters</b>                  | Additional contractual issues need to be resolved.                                                                                                                                                                                                                  | Contractual issues well-known                                                                                                                                                                                                                                                                  |
| <b>Aesthetics</b>                           | An appealing, uniform appearance can be difficult to achieve. However, such an achievement is not necessarily an indicator of a good result for Otta Seals.                                                                                                         | Ranges between a very appealing and a poor appearance depending on quality of construction workmanship.                                                                                                                                                                                        |
| <b>Skid resistance in wet weather</b>       | Poorer than a Chip Seal that is well designed and constructed using large chipping. However better than Slurry Seals and Asphalt Concrete.                                                                                                                          | Ranges between the extremes of excellent and very poor depending on quality of construction workmanship.                                                                                                                                                                                       |
| <b>Use on fresh bituminous base layers</b>  | Not suitable due to the need for high bitumen contents required for quick rise of the binder through the aggregate interstices.                                                                                                                                     | Suitable, but requires careful design and construction if excessive bleeding is to be avoided.                                                                                                                                                                                                 |
| <b>Periodic maintenance between reseals</b> | Generally little need for periodic maintenance between reseals.                                                                                                                                                                                                     | Rejuvenation with emulsion fog spray between reseals is normally required for maintaining stone retention.                                                                                                                                                                                     |
| <b>Durability of the seal</b>               | The use of relatively soft binders and a dense matrix enhances durability of seal.                                                                                                                                                                                  | The use of relatively hard binders reduces the durability of the seal.                                                                                                                                                                                                                         |
| <b>Typical service life</b>                 | Typical service life: <ul style="list-style-type: none"> <li>- Double Otta Seal: 12 - 15 years</li> <li>- Single Otta Seal with a sand cover seal: 9 - 11 years</li> </ul>                                                                                          | Typical service life : <ul style="list-style-type: none"> <li>- Double Chip Seal: 8 - 10 years</li> <li>- Single Chip Seal: 5 - 6 years</li> </ul> Adequately workmanship is essential                                                                                                         |

Table 4.1 Relative differences between Otta Seals and conventional Chip Seals.

## AGGREGATES

The general approach is to select the appropriate binder viscosity type and binder application rates to suit the available aggregate. Although the aggregate strength requirements are relaxed, it is always good practice to select the best quality of materials that are economically available in the project area.

Experience has shown that the best performance of an Otta Seal may be obtained when 30% of the aggregate is crushed. However, this should not be considered as “a rule of thumb”.



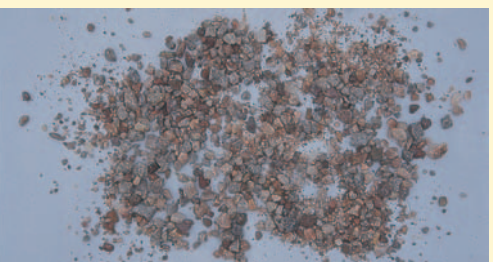
*“As dug material” which in many cases only requires screening of oversize materials, can successfully be used in Otta Seals. (Kenya).*



*Labour based methods can effectively be used in producing aggregate for use in Otta Seals. (Bangladesh).*



*Sophisticated and expensive crushing plant is normally required to produce aggregate for Chip Seals. (Norway).*



*The aggregate used in an Otta Seal make allowances for a wide range of particle sizes, from 16 mm and down.*

### 5.1 Key properties

A large variety of material sources can be used for the production of graded aggregate for use in Otta Seals. The following typical materials have been used as aggregate for Otta Seals with excellent performance:

- screened natural gravel from weathered granitic rocks;
- crushed and screened gravel from sandstone and lake deposits;
- screened river/lake gravel and sand;
- crushed, screened rock from a variety of rock types such as igneous rocks and pedogenic deposits of calcrete, silcrete and ferricrete.
- moraine, screened only and/or crushed;
- laterite and decomposed granite, screened to remove oversize;
- coral stone

#### Aggregate strength

Aggregates of relatively lower strength may be used for Otta Seals, compared to those typically specified for conventional Chip Seals (See Table 5.2).

#### Grading

The aggregate grading for Otta Seals is relatively relaxed and allows for a rather wide grading envelope. However, the grading curve of the aggregate should fall within the designated area and should be as “smooth” and parallel to the envelopes as possible. Table 5.1 gives the general grading requirements for Otta Seals.

### 5.2 Screened and crushed aggregates

‘As-dug’ gravel should be screened to remove oversize particles and excessive fines. A low moisture content in the material is desirable to avoid clogging of the finer mesh of the sieve. If moist material cannot be avoided, it may be necessary to increase the mesh size of the sieve. The presence of fines in the screened material is acceptable provided appropriate compensation is made for the binder viscosity, binder application rate and construction methodology.

#### Crushed gravel

The wide grading envelope requirement of Otta Seals allows a relatively higher proportion of the crushed product to be used compared to Chip Seals. Crushing allows a better utilisation of the gravel sources and generally improves the quality of the aggregate. The bulk of the crushed gravel product is normally utilised in Otta Seals resulting in little or no wastage. However, high establishment costs may prohibit crushing of gravel on smaller projects.

#### Crushed rock

Crushed rock is usually the most widely used type of aggregate for any surfacing in the country, including Otta Seals. A general rule of thumb is that any crushed material acceptable in the base course layer can be used to produce aggregate for an Otta Seal surfacing.

## 5.3 Aggregate for sand cover seals

A sand cover seal is normally recommended to apply over a single Otta Seal instead of using a double Otta Seal for low volume roads (< 500 AADT). The aggregate for the sand cover seal will normally consist of crusher dust or screened river sand or alternatively, fine pit sand can be used if no better material is available within an economical haulage distance.

## 5.4 Aggregate requirements

### General

The preferred aggregate grading will, to some extent, depend on the traffic volume at the time of construction, as well as during the two months immediately following the sealing operation, as this contributes significantly in forming the Otta Seal.

### Maximum particle size

The preferred maximum particle size is 16 mm, but 19 mm can be accepted in the first seal where a double seal is to be constructed.

### Fines content

The amount of fines (<0.075 mm) should preferably not exceed 10%. A higher fines content may result in construction problems, as the binder tends to coat the finer particles before the larger ones, and may lead to a less durable surfacing with inferior surfacing characteristics. However, aggregate with fines contents up to 15% have performed well on some projects, and no surfacing defects have yet been recorded due to excessive fines contents on any of these projects.

### General grading envelopes and aggregate strength

Table 5.1 shows the general material requirements for an Otta Seal and Figure 5.1 the general grading envelope. The aggregate strength requirements are shown in Table 5.2

| Material properties | Requirements                               | AASHTO or BS Test Designation |
|---------------------|--------------------------------------------|-------------------------------|
| Plasticity Index    | max 10                                     | T 90-61                       |
| Flakiness Index     | max 30 (applies only for crushed material) | BS 812                        |
| Sieve sizes [mm]    | Overall grading requirements [% passing]   |                               |
| 19                  | 100                                        | T 146-49                      |
| 16                  | 80 - 100                                   |                               |
| 13,2                | 52 - 100                                   |                               |
| 9,5                 | 36 - 98                                    |                               |
| 6,7                 | 20 - 80                                    |                               |
| 4,75                | 10 - 70                                    |                               |
| 2,00                | 0 - 48                                     |                               |
| 1,18                | 0 - 38                                     |                               |
| 0,425               | 0 - 25                                     |                               |
| 0,075               | 0 - 10                                     |                               |

Table 5.1 Material requirements for Otta Seals.

Where fine pit sand is used for the sand cover seal, this often results in a fatty appearance during the early life of the surfacing. However, the appearance improves with time and traffic to a good, coarse textured surface. The fine sand cover seal continues to protect and enhance retention of the aggregates in the underlying Single Otta Seal throughout its service life. Sand cover seals made of crusher dust or river sand are considerably more durable than the fine pit sand seal and provide an excellent finish.

The use of aggregate with a maximum size larger than 16 mm should preferably be avoided where possible as this may lead to loss of stones during service. This is specifically relevant when a Single Otta Seal is considered with only a sand cover seal on top.



*The fines content should ideally not exceed 10%. However, aggregate with fines content up to 15% has performed well in Otta Seals. (Botswana).*

Soft binders (e.g. MC800) are preferable where the fines content is relatively high.

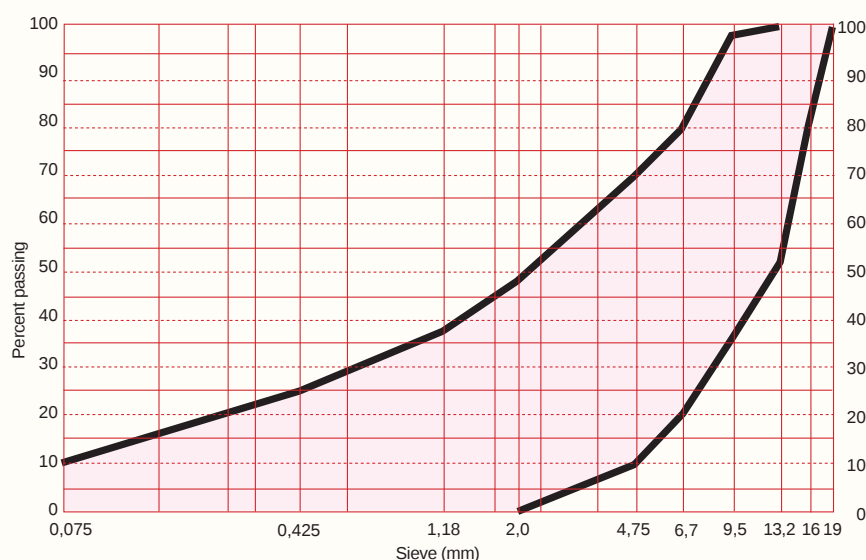


Figure 5.1 General grading envelope for Otta Seal aggregates

The required aggregate strength for Otta Seals is lower than that of a Chip Seal. Lower strengths can be tolerated because the graded particle matrix results in less internal pressure caused by stone to stone contact. The soft binders used in Otta Seals are, in addition, able to surround, coat and hold in place any particle that may break during rolling.

| Aggregate strength requirements | Vehicles per day at the time of construction |         | BS Test Designation |
|---------------------------------|----------------------------------------------|---------|---------------------|
|                                 | < 100                                        | >100    |                     |
| Min. Dry 10% FACT               | 90 k N                                       | 110 k N | BS 812              |
| Min. Wet/Dry strength ratio     | 0.60                                         | 0.75    |                     |

Table 5.2 Aggregate strength requirements for Otta Seals.

## Flakiness

No requirement for flakiness is specified for natural gravel or a mixture of crushed and natural gravel in Otta Seals. For crushed rock, it is preferable that the weighted Flakiness Index does not exceed 30. The weighted Flakiness Index is determined on the following fractions:

9,5 - 13,2 mm, 6,7 - 9,5 mm and 4,75 - 6,7 mm

## Sand cover seals

Material for a sand cover seal used in Otta Seals can be crusher dust, river sand or fine pit sand or a combination of these materials. The material should be free from organic matter and lumps of clay and should be non-plastic. All material should preferably pass the 6,7 mm sieve.

# BINDERS

# 6

## 6.1 Desirable characteristics

The correct choice of binder for Otta Seals is critical for its performance and a good result requires that both the binder type and application rate are tailored to the aggregate properties. Binders used for Otta Seals should:

1. be soft enough to initially coat the fines in the aggregate;
2. be soft enough to rapidly move up through the matrix of aggregate voids by the action of rolling and traffic;
3. remain soft long enough to continue moving up through the matrix of aggregate voids over a period of 4 to 8 weeks;
4. be able to be applied in a large enough quantity in one spray operation.

In addition to the above, the following binder properties are desirable in any bituminous seal. The binder must:

- be viscous enough to provide sufficient stability after the initial curing of the seal;
- be durable enough to give the expected service life;
- be able to be used with available equipment and skills;
- be environmentally friendly to the greater possible extent;
- be economical in use.

## 6.2 Types

A general description of selected binder types and their potential use in Otta Seals is given below.

### **Penetration grade bitumen**

80/100 or 150/200 penetration grade bitumen is normally used with conventional Chip Seals does not meet the requirements for Otta Seals and should NEVER be used for such surfacings. The hardest type of bitumen that can be used for Otta Seals is the 150/200 penetration grade which can be used under hot climate conditions (similar to summer periods on the African continent).

### **Cutback bitumen**

Cutback bitumen in the MC 3000 and MC 800 viscosity range are the most common binder used in the Otta Seals. MC 800 more often in northern Europe.

### **Bitumen emulsion**

Emulsions have never been used for Otta Seals on the African continent, although it has been used in the Scandinavian countries with limited success. Emulsions are generally difficult to apply in a large enough quantity without run-off along the road's cross fall or gradient, and do not remain soft for long enough unless produced especially for this purpose. Specially made emulsions from suppliers are, however, unlikely to be economical. Moreover, production of any type of emulsion on site is a specialised operation that entails quality control problems, hence this process is not recommended.

The selection of the binder type will depend on the aggregate properties, as well as the prevailing temperature conditions, rolling capacity and traffic volumes.

The graded aggregate used in Otta Seals possesses inherent stability making it easy to achieve the necessary stability of the seal without having to resort to the use of hard binders.

**Type of binders of paramount importance.**

**Correct viscosity range:**

**Normally MC 3000 or MC 800**

**but also pen. bitumen grade 150/200**

**80/100 pen. bitumen grade shall NEVER be used.**

Recent reports from South Africa (Louw & Jacobs, 1999) suggest that a semi-priming modified binder (SPMB) may be suitable for use with Otta Seals and could offer some advantages over conventional binders.

## **Tar**

Tar has not been used in Otta Seals because it tends to harden much more rapidly than bitumen, thus compromising the service life of the seal. Furthermore, tars have serious environmental disadvantages and their use in road surfacings is not recommended.

## **Modified bitumen**

Binders modified with rubber, SBS, SBR, PVA or other constituents have not been tried in Otta Seals. Any modified binders that are known on the market have too high a viscosity for use in Otta Seals and are therefore generally not suitable. In theory, however, there is no reason why a modified binder cannot be specially tailored to provide the properties that Otta Seals require, but such applications can only be recommended for trials.

## 6.3 Properties

### **Applicable binders for Otta Seals**

The range of acceptable binder viscosities for Otta Seals is provided by the following standard types:

- MC 800 cut back bitumen (softest)
- MC 3000 cut back bitumen (medium)
- 150/200 penetration grade bitumen (hardest)

These binders are very often available and are supplied directly from the refineries. The process of manufacture at the refineries varies. The 150/200 is often a softened (fluxed) 80/100 straight run bitumen. The cutbacks are frequently produced from a blown stock harder than 80/100 which has been cut back with a type of kerosene known locally as power paraffin to give the required viscosity.

### **Durability of cutback bitumen**

The long-term durability of manufactured cut back bitumen (MC 3000 and MC 800) that is available locally is not always acceptable. This is due to the production process which entails blending from a hard base bitumen.

Improved durability is achieved by producing cut back bitumen on site from a softer base bitumen such as 150/200 or 80/100 penetration grades, rather than using cutbacks supplied directly from the manufacturers.

## 6.4 Blending on site

### **General**

Blending of bitumen on site may be desirable for one or more of the following reasons:

- to obtain the required viscosity of cutback bitumen (by cutting back with an appropriate cutter);
- to enable use of a preferred type of base bitumen;
- to 'permanently' soften a penetration grade bitumen that is too hard (by fluxing);



*Cutting back to improve the viscosity and binder properties is possible, even under «primitive» conditions. (Bangladesh).*

- to improve the durability of a bitumen (by fluxing);
- to simplify handling and storage where a number of binder types are required on the same site (by cutting back or fluxing).

## Cutters

Cutting back is the addition of volatile oils to produce a temporary reduction of the binder's viscosity. The volatility of the cutter used will influence the type of cut back bitumen that will be produced in terms of whether it is rapid, medium or slow curing.

Table 6.1 shows the cutters that produce the respective types of cutback bitumen.

| Grade of the produced cutback | Cutter                                                                             | Notes                                  |
|-------------------------------|------------------------------------------------------------------------------------|----------------------------------------|
| RC<br>(Rapid Curing)          | Petrol                                                                             | Hazardous, should not be used          |
| MC<br>(Medium Curing)         | Kerosene (Power paraffin<br>Illuminating paraffin, JetA1<br>aviation turbine fuel) | Suitable for Otta Seals                |
| SC<br>(Slow Curing)           | Diesel or heavy fuel oils                                                          | Curing process too slow for Otta Seals |

Table 6.1 Cutters.

An Otta Seal will in most cases require a cutter that produces a medium curing (MC) cutback bitumen. Power paraffin is normally preferred among the cutting oils producing a MC cutback bitumen. Illuminating paraffin and JET A1 may also be used depending on the prevailing price.

## Flux oil

Fluxing is the addition of heavy oil that affects the long-term viscosity and durability of the binder. Fluxing slows down the hardening process of the bitumen and, within certain limits will produce a more durable seal. Engine oil, unused or used, is suitable for this purpose. Fluxing should be carried out in moderation, as there is a risk of disintegration of the seal if the binder is excessively fluxed.

## Blending proportions

The cutter proportions presented in Table 6.2 are indicative for blending with the penetration grades 80/100 or 150/200 respectively.

## Safety precautions

Blending of cutback bitumen on site may be hazardous. Correct procedures should be followed during blending and appropriate safety precautions against fire and hot bituminous spray should be taken to safeguard personnel involved in the operations. Precautions are also necessary to ensure that the public is kept at a safe distance from the blending site.

The viscosity of the medium curing (MC) cutback bitumen (e.g. MC 3000, MC 800, MC 70, MC 30) is determined by the amount of cutter used, not the type of cutter.

The type of cutter used determines the length of time (Rapid, Medium or Slow) required for evaporation of the volatiles to take place, producing RC, MC or SC grades.

Under normal circumstances MC cutters will evaporate from the seal within 8 - 12 weeks.

Diesel as a cutter will produce a slow curing (SC) cutback bitumen that remains soft over a long period. Evaporation may take in excess of six months to occur and will cause unnecessarily prolonged bleeding and, at worst, instability of the seal.



*Correct procedures must always be followed when cutting back on site as such operations may be hazardous. Otherwise, fire may be the result. (Bangladesh).*

Flux oil is less flammable than cutters, nonetheless, for safety reasons on site, it is good practice to always handle both flux oils and cutters with similar precautions.

Some re-heating may be necessary to reach spraying temperature after blending of the bitumen. However, if prime is the desired product then re-heating is normally not necessary.

| Required product                                                                                                                                                 | Cutter (power paraffin) in percent of total mixture |                      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|----------------------|
|                                                                                                                                                                  | 80/100 base bitumen                                 | 150/200 base bitumen |
| 150/200                                                                                                                                                          | 3-5% (flux oil is used instead of cutter)           | -                    |
| MC 3000                                                                                                                                                          | 8 - 10 % *)                                         | 5 - 8 %              |
| MC 800                                                                                                                                                           | 18 - 20 % *)                                        | 15 - 18 %            |
| *) The durability of the binder can be improved by replacing 3% - points of the cutter with flux oil where the 80/100 penetration grade is used as base bitumen. |                                                     |                      |

*Table 6.2 Typical blending proportions to produce medium curing cutback bitumen.*

The following safety precautions should be adhered to:

- The blending site shall be located at a minimum distance of 100 metres from installations, homes or places that people occupy
- No open fire or smoking shall be allowed during the blending operation within a radius of 100 metres. This includes heaters in bitumen tanks;
- The blending site should be at least 100 metres away from cutter and fuel storage tanks.

It is emphasised that the blending process shall be kept fully under the responsibility of qualified personnel.

### **Blending operations**

Cutter or flux oil 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 or flux oil 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 or flux oil. The following precautions should be strictly adhered to as the blending operation is a hazardous one and causes considerable risk of explosion and fire.

The manhole should NEVER be used for adding cutter or flux oil to hot bitumen;

- Cutter or flux oil 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 or flux oil the mixture shall immediately be circulated for 1 hour in order to ensure a homogenous product.

## 6.5 Temperatures for storage and spraying

Recommended temperatures for storage and spraying of binders are shown in *Table 6.3*.

| Bitumen product | Storage temp. °C |            | Spraying temp. °C |
|-----------------|------------------|------------|-------------------|
|                 | < 24 hours       | > 24 hours |                   |
| 150/200         | 165              | 115        | 165 - 180         |
| MC 3000         | 155              | 100        | 135 - 155         |
| MC 800          | 120              | 75         | 110 - 135         |

*Table 6.3 Recommended storage and spraying temperatures.*

## 6.6 Anti-stripping agent

### General

The adhesion between bitumen and aggregate depends on close contact between the two materials. Stripping is the breaking of the adhesive bond between the aggregate surface and the bitumen, normally by water displacing the bitumen because water has greater surface tension than bitumen. By adding a comparatively small quantity of anti-stripping agent to the bitumen, the surface tension of the water is reduced and the bitumen is able to wet aggregate surfaces. In general, adhesion agents are intended to:

- promote adhesion of binder to wet aggregate;
- prevent loss of adhesion under influence of immediate rain after construction;
- provide satisfactory adhesion during construction.

The use of anti-stripping agent is always recommended when using natural gravel with a high fines content. However, good performance has been reported without the use of additives. When crushed material is used, appropriate laboratory testing should be carried out to identify the need for anti-stripping agent.

### Handling and dosage of anti-stripping agents

Anti-stripping agents are usually corrosive and require the use of protective gloves and eye goggles during handling. Liquid agents can easily cause splashing and require special care. Some 'solid' agents may appear in a liquid form, depending on ambient temperature, and should be treated with equal caution.

Normal dosage of anti-stripping agent is 0,5% to 0,8% by weight of bitumen. Appendix A gives the Mass/Volume conversion tables.

The most common method of achieving the admixture is to pour the calculated amount of additive into the bitumen distributor immediately before the spraying operation is to start and to allow 30 minutes of circulation to ensure a homogenous mix.

Anti-stripping agents that have been kept hot in the bitumen distributor for more than five hours should be considered stale. An additional dosage would then be required, amounting to half of the originally specified percentage.

Cutback bitumen should not be held at spraying temperature for periods exceeding 12 hours. This will cause loss of light oil fractions and an undesirable change in binder properties.

Anti-stripping agents are expensive products and should only be used when absolutely necessary.

Anti-stripping agents are sold under a variety of brand names.

A wire basket suspended inside the bitumen distributor will ease the dissolving problem if a solid anti-stripping agent is used.

There are a variety of anti-stripping agents on the market, of which some are less adversely affected by high temperatures than others

# 6

*I wonder if this priming is necessary, when they are putting down an Otta Seal ???*



Priming can, in some instances, provide practical benefits for reasons such as wet weather conditions, problems with traffic control or as a preferred construction procedure for operational reasons. However, Otta Seals do not require priming of the base course to function well.

## 6.7 Prime

### **General**

Priming of base courses made of non-calcareous material is normally not required when using Otta Seals. However, when using calcrete of any type in the base course, priming is warranted due to the high amount of bitumen absorption.

### **Types of prime**

Cutback bitumen with a viscosity in the range 30 - 140 cSt (MC 30 or MC 70) is normally used for priming. Tar primes have serious environmental disadvantages and are not recommended for use as primes.

### **Application rate**

A prime is normally applied at an application rate of between 0.8 and 1.2 l/m<sup>2</sup>. Calcareous base courses require application rates in the high range and a lower viscosity of the prime than other types of base course material. High soluble salts content in the base course require high application rates or the use of an emulsion tack coat.

# SURFACING SELECTION CRITERIA



## 7.1 Factors influencing choice of surfacing

There are a number of factors that need to be taken into account when selecting the most appropriate type of bituminous seal. This will always be the case whether it is new construction, rehabilitation or reseal work. The initial construction cost for various types of bituminous surfacings depends on a variety of factors including the cost of prospecting for aggregate and the construction methodology adopted. In addition to initial construction costs, maintenance and vehicle operating costs should be considered as well (e.g. life-cycle cost) as a basis for selecting the most cost-effective surfacing type.

## 7.2 Life expectancy

Different types of surfacings will provide different service lives for given site conditions. Table 7.1 shows the life expectancy for the various types of Otta Seal and a Double Chip Seal. These have been derived from experience gained in Norway, Kenya and Botswana.

| Type of Otta Seals                      |                                                   | Expected service life [years]                                                  |
|-----------------------------------------|---------------------------------------------------|--------------------------------------------------------------------------------|
| Single Otta Seal                        | No cover seal                                     | 5-6 *, but may vary depending on type of surfacing and quality of workman-ship |
| Single Otta Seal with a sand cover seal | Fine sand in the sand cover seal                  | 9 - 11                                                                         |
|                                         | Crusher dust or river sand in the sand cover seal | 10 - 12                                                                        |
| Double Otta Seal                        |                                                   | 12 - 15                                                                        |
| Double Chip Seal                        |                                                   | 6 - 10                                                                         |
| Frequency of rejuvenation (fog spray)   |                                                   | 2 - 3                                                                          |
| * As experienced in Norway              |                                                   |                                                                                |

Table 7.1 Life Expectancy for various types of Otta Seals and a Double Chip Seal.



*A single Otta Seal with a sand cover seal. After more than 9 years in service and without any surfacing maintenance the surfacing performs excellently. (Botswana).*

*Otta Seals have proved to be more durable than other conventional surface treatments in appropriate circumstances.*

This Guideline does not describe in detail the procedures required to calculate total life-cycle costs, but such calculation models are readily available in handbooks for pavement management and rehabilitation.

## 7.3 Economic assessment of Otta Seals versus Chip Seals

An economic assessment of the alternative surfacing seals should always be carried out in order to select the most cost-effective solution.

As different seals vary in construction cost, and give varying maintenance-free lives, an economical comparison between a Double Chip Seal and the various type of Otta Seals should not only consider the initial construction costs, but also include the cost of required future maintenance such as rejuvenation (fog spray) reseals and road markings over an appropriate analysis period.

In order to obtain life-cycle costs for alternative surfacing types the following are required for the calculations:

- Initial construction cost;
- Fog sprays (number required and cost);
- Reseals (number required and cost);
- New road markings after each intervention (number required and cost);
- Discount and inflation rates.

The relative construction cost of a Double Otta Seal with a cover sand seal compared with a Double Chip Seal (cost factor 1.0) may in general be described as presented in Table 7.2. However, this relative construction cost comparison may differ considerably from country to country, as well as between projects. The figures in Table 7.2 is based on data from Botswana.

| Project Features                                         | High traffic<br>AADT > 500 | Low traffic<br>AADT < 500 |
|----------------------------------------------------------|----------------------------|---------------------------|
| Long haulage of acceptable chipping (> 100 km)           | 0,8                        | 0,7                       |
| Quarry sites for chipping are close to project (< 25 km) | 1,1                        | 1,0                       |

Note: The cost of a Chip Seal = 1,0

*Table 7.2 Relative construction costs of a Double Otta Seal and a Double Chip Seal .*

All types of surfacing seals will normally lend themselves to simple, although different maintenance techniques such as fog spraying, resealing or slurry sealing. Fog sprays with diluted emulsion have been found to be cost-effective for Chip Seals where the seal is beginning to ravel. If this is done before the seal starts to disintegrate, the service life of the seal can be prolonged.

The life-cycle maintenance strategy for Otta Seals and Chip Seals have been compared and may in general be described as is in Table 7.3. Again, this may differ considerably between the different countries. The figures in Table 7.3 is based on maintenance intervention adopted in Southern Africa.

| Life expectancy, activities and construction costs                                                                                                                                                                                | Otta Seals          |        | Double Chip Seal                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|--------|--------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                   | Single + sand cover | Double |                                                                                                        |
| Life expectancy (years)                                                                                                                                                                                                           | 11                  | 15     | 7                                                                                                      |
| Maintenance activities (years)                                                                                                                                                                                                    | None                | None   | Fog sprays after 3 and 10 years. Reseal after 8 years. Road marking after each intervention (4 times). |
| Initial relative cost of construction                                                                                                                                                                                             | 1.0                 | 1.2    | 1.2                                                                                                    |
| Chipping size used for 11 and 15 years analysis period 13.2 mm + 6.7 mm and 19.0 mm + 13.2 mm respectively.                                                                                                                       |                     |        |                                                                                                        |
| To simplify the life-cycle cost analysis it has been assumed that no other type of maintenance will take place during the analysis period and that vehicle operation costs are the same for both Otta Seals and Double Chip Seal. |                     |        |                                                                                                        |

*Table 7.3 Maintenance intervention for lifetime cost comparison of different type of seals.*

A life cycle cost analysis over a 20 years period from Botswana (August 1999) based on maintenance interventions as seen in Table 7.3 using discounted cash flow techniques, and employing the Present Worth Method of economic analysis. This method involves the conversion of all costs incurred in the construction and subsequent maintenance of the seal, including the provision of road marking to common 1999 base year of Net Present Value (NPV) costs. It is assumed vehicle operation costs are similar for both seals.

This calculation gave a life cycle cost of the conventional Double Chip Seal that was approximately 80% higher than for the Single Otta Seal plus a sand cover seal. As is apparent, the cost advantage of the latter over the former is derived mainly as result of lower initial costs, longer seal life and less maintenance interventions. The differences would be even greater if any haulage of aggregate is involved or if screened natural gravel within the project area were used for the Otta Seal rather than crushed aggregate.

## DESIGN

### 8.1 Factors influencing the design

The design of Otta Seals is based on empirical methods, rather than the more rational methods used for Chip Seals.

The principles governing the design of Otta Seals are based closely on the inter-relationship between the aggregate used and the binder viscosity and spray rates adopted, which means that the binders used will always be tailored to the type of aggregate produced.

Otta Seals may be constructed as a single or double layer, with or without a sand cover seal, and the choice of a particular type of Otta Seal is normally based on the following considerations:

- properties of available aggregate
- traffic volume
- construction cost
- required service life

In the design of Otta Seals, the type of bitumen and the bitumen spray rates are initially established based on typical values of the main parameters determining the design. Variations in the site conditions or aggregate grading at the time of construction may require adjustments of spray rates on site. Changes in binder viscosity may also be necessary where the variations in site conditions or materials are significant.

The procedures to be followed in the design of Otta Seals are shown as a flow chart in Figure 8.1

### 8.2 Selection of Otta Seal type

#### ***Double Otta Seal***

The Double Otta Seal is the most durable, but also the most expensive and is recommended for main roads carrying high volumes of traffic. Double Otta Seals with a cover sand seal are seldom specified due to their high costs and marginal benefits.

#### ***Single Otta Seal with sand cover seal***

The combination of a Single Otta Seal followed by a sand cover seal is a cheaper option than a Double Otta Seal. The service-life will however, be shorter, but the former provides a very cost-effective solution for roads with AADT generally less than 500. The benefits of using a sand cover seal are the following:

- 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;
- reduced risk of damage in the case of imperfections in the underlying seal.

Otta Seals allow for the use of a variety of aggregate gradings. The binder viscosity and spray rate are selected to suit the aggregate grading, traffic conditions and temperature at the time of construction. Decisions taken at that time of construction largely determine the performance of the Otta Seal during its service-life.

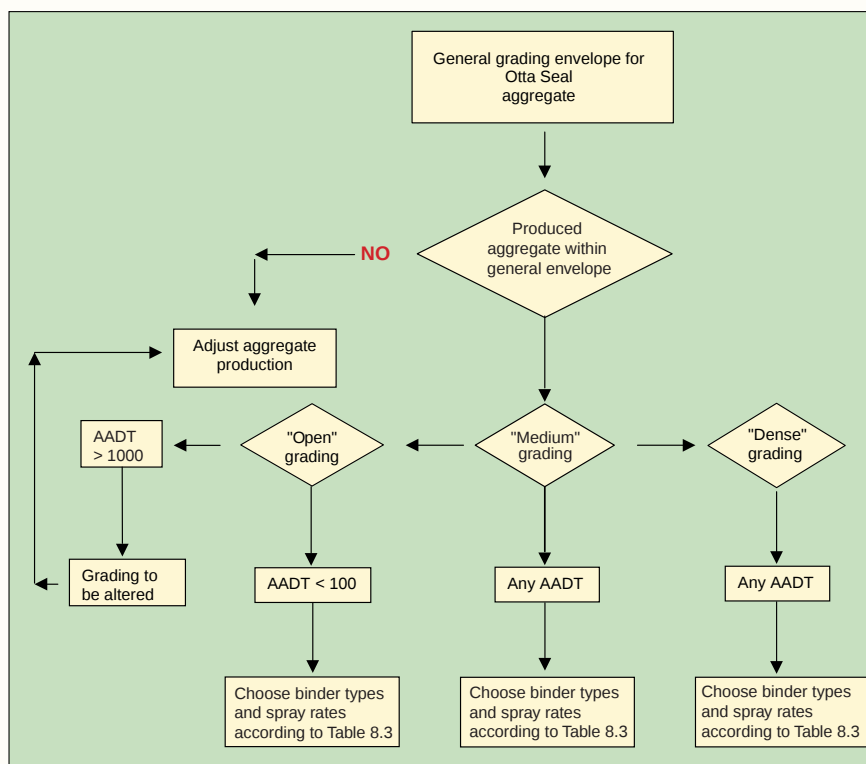


Figure 8.1 Flow chart for the design procedures of Otta Seals.

### Single Otta Seals

Single Otta Seals are not commonly used on the African continent. However, in north Europe and in Bangladesh single Otta Seal is used.

Table 8.1 shows recommended Otta Seal types in relation to traffic level and the type of sealing work to be carried out. However, the given recommendations are flexible and will be project dependent.

| Traffic levels and type of work                                                         | Type Otta Seal                     |
|-----------------------------------------------------------------------------------------|------------------------------------|
| Temporary seal (diversions, haul roads, temporary accesses, etc.).                      | Single Otta Seal                   |
| Maintenance resealing (all traffic classes to which sprayed surfacings are applicable). | Single Otta Seal                   |
| AADT less than 500                                                                      | Single Otta Seal + sand cover seal |
| AADT more than 500                                                                      | Double Otta Seal                   |

Table 8.1 Recommended type of Otta Seal in relation to traffic levels.

## 8.3 Preferred aggregate grading

The design of Otta Seals allows for a variety of aggregate gradings to be used as long as the grading curve falls within the designated area of the general grading envelope (ref. Figure 5.1) and runs as “smoothly” and parallel to the envelope as possible.

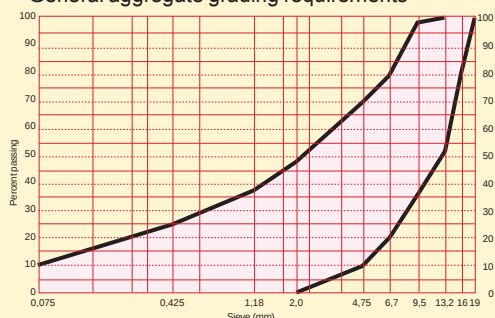
As guidance for the designer of Otta Seals, three grading envelopes, depending on traffic, have been produced to allow for a more rational design. However,

For the coarser aggregate type used in the Otta Seal it may be beneficial to water the aggregate stockpile 3-4 days before use.

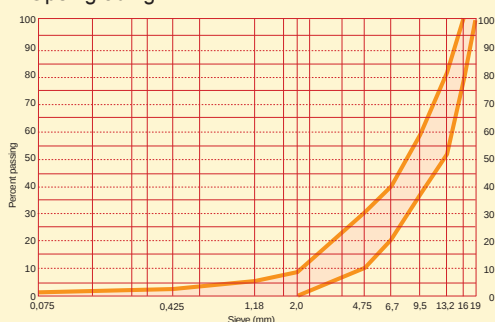
The aggregate application rates for an Otta Seal will appear excessive in comparison with that for a conventional Chip Seal

# 8

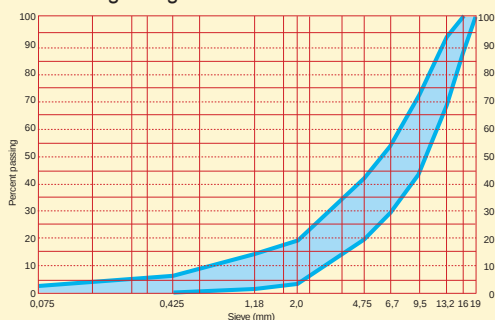
## General aggregate grading requirements



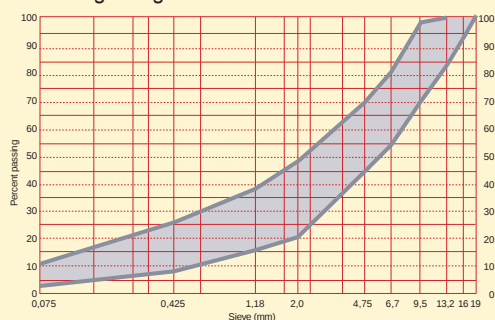
## Open grading



## Medium grading



## Dense grading



The binder application rates are relatively higher for Otta Seals than for conventional Chip Seals. The hot spray rates of binder normally fall within the range of 1,6 - 2,0 l/m<sup>2</sup>. (Kenya).

the designer should always bear in mind that generally all types of aggregate which fall within the general specified envelope can be used, provided the binder viscosity and spray rates are tailored accordingly.

The only limitation regarding the aggregate grading used in an Otta Seal is with regard to the “Open” grading which should not be used for traffic volumes above AADT 1000.

Table 8.2 indicates the preferred aggregate grading for design purposes according to traffic volume.

| AADT           | Best suited grading |
|----------------|---------------------|
| Less than 100  | "Open"              |
| 100 - 1000     | "Medium"            |
| More than 1000 | "Dense"             |

Table 8.2 Preferred aggregate grading for Otta Seals

The grading envelopes for “Open”, “Medium” and “Dense” grading are given Table 8.3a, the design procedure for Otta Seals.

## 8.4 Type of binder

Table 8.3 shows the recommended type of binder for Otta Seals made with the three respective aggregate gradings under typical site conditions on the African continent, as described in the table. Under normal Scandinavian site conditions 150/200 penetration grade bitumen is not used for Otta Seals.

Where “weak” natural gravel containing a fairly high proportion of fines is used the correct binder type will be MC 3000 or even

MC 800 viscosity range, depending on weather conditions.

It should be noted that in Table 8.3a MC 3000 viscosity grade bitumen is recommended for use with “Medium” grading aggregates under cold conditions (temperatures below 15°C).

## 8.5 Binder spray rates

The required binder spray rates for Otta Seals varies according to the following parameters:

- traffic (AADT)
- aggregate grading (open / medium / dense)
- the absorbency of the aggregate particles
- whether the base course is primed or not

Hot spray rates lower than 1,5 l/m<sup>2</sup> should not be allowed.

For aggregates with a water absorbency of more than 2%, the hot spray rate should be increased by 0,3 l/m<sup>2</sup>.

In the case where the base has been primed the hot spray rate should be decreased by 0,2 l/m<sup>2</sup> for the first layer.

Table 8.3b gives the nominal hot spray rates for Otta Seals.

## 1. ALTERNATIVE GRADING ENVELOPES

| Sieve sizes<br>(mm) | Open grading | Medium grading | Dense grading | AASHTO or<br>BS Test<br>designation |
|---------------------|--------------|----------------|---------------|-------------------------------------|
|                     | (% passing)  | (% passing)    | (% passing)   |                                     |
| 19                  | 100          | 100            | 100           | T 146-49<br>BS 1377                 |
| 16                  | 80 – 100     | 84 – 100       | 93 – 100      |                                     |
| 13,2                | 52 – 82      | 68 – 94        | 84 – 100      |                                     |
| 9,5                 | 36 – 58      | 44 – 73        | 70 – 98       |                                     |
| 6,7                 | 20 – 40      | 29 – 54        | 54 – 80       |                                     |
| 4,75                | 10 – 30      | 19 – 42        | 44 – 70       |                                     |
| 2,00                | 0 – 8        | 3 – 18         | 20 – 48       |                                     |
| 1,18                | 0 – 5        | 1 – 14         | 15 – 38       |                                     |
| 0,425               | 0 – 2        | 0 – 6          | 7 – 25        |                                     |
| 0,075               | 0 – 1        | 0 – 2          | 3 – 10        |                                     |

Any material falling within the Open, Medium and Dense grading envelopes may be used as aggregate in an Otta Seal. However, for a traffic level AADT > 1000 vpd. at the time of construction material within the Open grading envelope shall NOT be used.

## 2. CHOICE OF BITUMEN IN RELATION TO TRAFFIC AND GRADING

| AADT at the<br>time of<br>construction | Type of bitumen    |                                       |                                      |  |
|----------------------------------------|--------------------|---------------------------------------|--------------------------------------|--|
|                                        | Open grading       | Medium grading                        | Dense grading                        |  |
| More than 1000                         | Not applicable     | 150/200 pen. grade                    | MC 3000<br>MC 800 in cold<br>weather |  |
| 100 - 1000                             | 150/200 pen. grade | 150/200 pen. grade in<br>cold weather | MC 3000<br>MC 800 in cold<br>weather |  |
| Less than 100                          | 150/200 pen. grade | MC 3000                               | MC 800                               |  |

80/100 pen. grade bitumen shall NEVER be used in Otta Seals unless softened or cut back to meet the above viscosity requirements.

**The cut back bitumen grades can be made by blending 80/100 pen. grade on site using the following proportions:**

To make 150/200 pen. grade: 3 - 5% softener mixed with 95 - 97 % 80/100 pen. grade.  
Softener can be a purpose-made petroleum distillate, alternatively engine oil, old or new. In addition 3% points of power paraffin shall be used.

**The cut back bitumen grades can be made by blending 150 /200 pen. grade on site using the following proportions:**

To make MC 3000: 5 - 8% power paraffin mixed with 92 - 95% 150/200 pen. grade.  
To make MC 800: 15 - 18 power paraffin mixed with 82 - 85% 150/200 pen. grade.

Circulation in the tank shall be carried out for at least 1 hour after mixing.

Table 8.3 a Design procedures for Otta Seals.

## 3. BITUMEN SPRAY RATES

Hot bitumen spray rates for un-primed base course (l/m<sup>2</sup>)

| Type of Otta Seal \ Grading    |                                   | Open | Medium | Dense     |           |
|--------------------------------|-----------------------------------|------|--------|-----------|-----------|
|                                |                                   |      |        | AADT <100 | AADT >100 |
| Double                         | 1 st layer                        | 1,6  | 1,7    | 1,8       | 1,7       |
|                                | 2 nd layer (*)                    | 1,5  | 1,6    | 2,0       | 1,9       |
| Single, with a sand cover seal | Fine sand                         | 0,7  | 0,7    |           | 0,6       |
|                                | Crusher dust or coarse river sand | 0,9  | 0,8    |           | 0,7       |
|                                | 1 st layer (*)                    | 1,6  | 1,7    | 2,0       | 1,9       |
| Single (*)                     |                                   | 1,7  | 1,8    | 2,0       | 1,9       |
| Maintenance reseal (single)    |                                   | 1,5  | 1,6    | 1,8       | 1,7       |

(\*) On a primed base course the spray rate shall be reduced by 0,2 l/m<sup>2</sup> in the first layer.

- Notes:
- Where the aggregate has a water absorbency of more than 2%, the bitumen spray rate shall be increased by 0,3 l/m<sup>2</sup>.
  - Binder for sand cover seal shall be MC 3000 for crusher dust or coarse river sand, MC 800 for fine sand

## 4. AGGREGATE APPLICATION RATES

| Type of seal     | Aggregate spread rates (m <sup>3</sup> /m <sup>2</sup> ) |                |               |  |
|------------------|----------------------------------------------------------|----------------|---------------|--|
|                  | Open grading                                             | Medium grading | Dense grading |  |
| Otta Seals       | 0,013 – 0,016                                            | 0,013 – 0,016  | 0,016 – 0,020 |  |
| Sand cover seals | 0,010 – 0,012                                            |                |               |  |

In practice, the aggregate application rates will very often be increased in order to reduce the risk of bleeding.

Table 8.3 b Design procedures for Otta Seals.

## 8.6 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 2-3 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 8.3b

Table 8.3b gives the criteria for selection of bitumen type and spray rates for the design of Otta Seals. No correction of bitumen spray rates should be made in the design to compensate for the solvent used in the cutback bitumen

In contrast to the procedures adopted for the design of Chip Seals on shoulders, no special design procedure is required for Otta Seals on shoulders.



A too excessive aggregate application. (Botswana).



Correct aggregate application rate. (Botswana).

# CONSTRUCTION

# 9

## 9.1 General

The construction of Otta Seals is generally similar to the conventional Chip Seal. The binder is sprayed onto the surface followed by the spreading and rolling of the aggregate. However, the use of prime is not essential for Otta Seals.

## 9.2 Preparation of base course

### General

A good bond between the base course and the surfacing is as important for Otta Seals as for any bituminous seal.

### Un-primed base course

The base course should be broomed free of all dust or any other foreign matter before commencing the surfacing operations. In order to suppress any dust, and to promote some penetration into the base course, it is necessary to carry out light watering prior to spraying the binder. After watering, the base course should be allowed to dry to a dampened state before the binder is sprayed.

### Primed base course

The preparation of a primed surface for construction of Otta Seals is similar to good practice procedures adopted for placing any bituminous seal.

## 9.3 Sealing operations

### General

In the construction of Otta Seals the following factors should be given particular attention:

### On the day of construction

A rule of a thumb is to assume that a good result would have been achieved when one can see bitumen being pressed up in-between the aggregate particles, sparsely distributed in the wheel tracks of the chip spreader or truck wheels.

Sufficient rolling of the Otta Seal cannot be over-emphasised. A minimum of two pneumatic tyred rollers at a minimum weight of 12 tonnes or more are essential at the day of construction, as they have a superior ability to knead the binder upwards into the aggregate particles, and to apply pressure over the entire area. A minimum of 15 passes with a pneumatic tyred roller is required over the entire surface area, shoulders included, on the day of construction.

After the initial rolling is completed (on the day of construction) it may be an advantage to apply one pass with a 10-12 tonnes static tandem steel roller to improve the embedment of the larger aggregate. During this process any weak aggregate will be broken down and will contribute to the production of a dense matrix texture.

Like all other surface treatments, an Otta Seal will not contribute directly to the structural strength of the pavement. The pavement must therefore be properly designed and constructed to withstand the expected traffic loading throughout its design life.

The preparatory work for construction of the first Otta Seal layer when prime is not used is similar to the preparatory work before construction of a prime on a conventional Chip Seal. On a dry or dusty base course the binder will contract ("ball up") and leave spots un-covered by bitumen thus causing potholes to develop.



*Preparatory work prior to sealing operation, clearing loose material from the base. (South Africa).*



*Light watering of the broomed base before spraying the binder will enhance the bond between the base and the Otta Seal. (South Africa).*

Surplus cover material is always needed in the construction of an Otta Seal, and it is important to ensure that the aggregate application rate is sufficient to accommodate this requirement (ref. Chapter 8.6).



*Otta sealing operations. Enough aggregate is essential in order to allow the binder to work its way upwards to coat all the particles. (Botswana).*

# 9



Extensive rolling with pneumatic rollers is essential to achieve a good result. (South Africa).



One pass with a static tandem steel roller will improve the embedment of the larger aggregate.



In the absence or in addition to pneumatic rollers, compaction can be successfully carried out by the use of loaded trucks following a pre-determined rolling pattern covering the entire surfaced area. (Botswana).



Otta Seal surfacing, 2 - 3 days after construction, and where traffic has been allowed using the surfacing immediately after construction. (Botswana).



Aggregate that has been dislodged by traffic should be broomed back into the wheel paths. This to ensure maximum embedment of the aggregate into the soft binder. (Botswana).

| Rolling after treatment                                                                                                                                                                                                   | Minimum requirements                                                                        |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| On the day of construction                                                                                                                                                                                                | 15 passes with pneumatic roller (weight > 12 tonnes)<br>+ 1 pass with a static steel roller |
| For each of the next two days after construction                                                                                                                                                                          | 15 passes with pneumatic roller (weight > 12 tonnes)                                        |
| 2-3 weeks after construction                                                                                                                                                                                              | Sweep off any excess aggregate                                                              |
| Note: During construction a minimum of two pneumatic tyred rollers are required. One pneumatic tyred roller will either delay the surfacing operations or worse, not be able to roll the newly laid surfacing sufficient. |                                                                                             |

Table 9.1 Minimum rolling requirements.

Commercial traffic should be allowed on the surfaced area immediately following completion of the initial rolling with the pneumatic roller(s). This will assist further in the kneading of the binder/aggregate admixture.

A maximum speed limit of 40 - 50 km/hour should be enforced immediately after construction and sustained for 2 - 3 weeks when any excess aggregate should be swept off.

## 9.4 Follow-up inspections

It is essential that follow-up inspections of the Otta Seal surfacing are carried out to ensure that any defects that may have occurred during the sealing operation are corrected.

An inspection must be made during the first 6 - 7 days following sealing, particularly if there is a major change in the weather conditions e.g. rainfall or an extreme change of temperature. A sudden change in traffic loading may also affect the newly constructed surfacing.

## 9.5 Immediate post-construction care

To successfully construct an Otta Seal, immediate post-construction care is important and should not be neglected. This includes additional rolling and brooming back of the aggregate that has been dislodged by traffic.

### *The initial two days after construction*

During the first two days after sealing, extensive rolling by pneumatic rollers shall take place in order to ensure that all particles embedded in the binder are properly coated. A minimum of 15 passes with the pneumatic tyred roller shall be applied daily, covering the entire surfaced area.

### *Subsequent 2 - 3 weeks after construction*

Aggregate that has been dislodged by traffic during the immediate post-construction period should be broomed back into the wheel tracks as required during the first 2 - 3 weeks. This ensures that maximum amounts of aggregate particles are embedded into the soft binder. A newly constructed Otta Seal may be dusty and could produce "flying stones" for the first few weeks after construction.

2 - 3 weeks after construction, any excess aggregate can be swept off and the traffic speed limitations can be lifted. If natural gravel with a fairly high content of fines is used the period should be prolonged.

## **The period up to 12 weeks after construction**

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, 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 blinded off with aggregate and preferably rolled into the surfacing. Signs of slight bleeding confirm that the aggregate/binder ratio has been optimal.

If natural gravel having a fairly high fines content is used, the period before sweeping off the excess gravel should be prolonged as long as possible, and not less than 6 - 8 weeks.

### **Bleeding**

Some bleeding in localised areas and in the wheel paths is a normal part of the curing process for Otta Seals. Any available fine aggregate can be used for blinding off, such as crusher dust, river sand or fine pit sand. Where bleeding is extensive, a coarse aggregate may be used. It is advisable to apply rolling when blinding off the surface and to choose the hot time of the day for this work.

## **9.6 Traffic management**

Traffic control is an important aspect that should not be overlooked as the early trafficking is a valuable contribution to the curing of the seal, leading to its enhanced performance.

The traffic management should be carried out in such a manner that the entire surfaced area, including shoulders, is equally exposed to traffic. This can be achieved by forcing the traffic into designated artificial lanes marked by traffic cones or similar.

## **9.7 Additional considerations for Double Otta Seal and combination seals**

### **General**

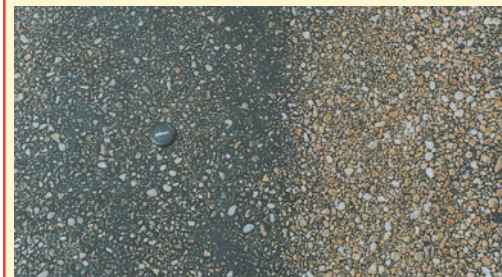
Special attention to certain details is required during construction of Double Otta Seal and combination seals using a sand cover seal.

### **Curing**

It is important that the curing of the 1<sup>st</sup> seal is allowed to continue for a minimum of 8 - 12 weeks, depending on curing conditions and binder type, before applying the following seal. This is required to minimise prolonged fattening up due to cutter oil from the binder.



*After a period of 8 - 10 weeks (traffic dependent), the Otta Seal beds down to produce the appearance of an asphaltic concrete premix. (Botswana).*



*Close-up, after 8 - 10 weeks the aggregate beds down. (Botswana).*



*Some bleeding in localised areas and in the wheel paths form a normal part of the curing process. Severe bleeding can be rectified by sand or additional aggregate rolled into the bleeding areas. (Botswana).*

The surplus aggregate is valuable material that should be collected and recycled for use in subsequent sealing operations.



*The Otta Seal should preferably be equally exposed to traffic over the entire sealed area as this will enhance an uniform appearance. This can be achieved by the use of traffic cones to direct the traffic in to areas that need trafficking. (Botswana).*

# 9



*Over application of sand is essential when applying a sand cover seal on top of a single Otta Seal. (Botswana).*



*The sand blown off by traffic should be broomed back into the exposed areas until full embedment is achieved. (Botswana).*



*An Otta Seal will apparently show a significant difference visually between the shoulders and the carriageway. The traffic in the carriageway area works the binder upwards to the surfacing and hence, making difference in colour. This difference in colour will improve the traffic safety aspect. (Botswana).*



*After some months the Otta Seal with a sand cover seal are fully settled and shows excellent appearance. (Botswana).*

## **Sand cover seal**

The most important factors to be observed in constructing a sand cover seal are to ensure that enough cover aggregate is applied, and that aggregate dislodged by traffic is broomed back into the exposed areas as required. The back brooming should be repeated regularly until the sand is fully embedded in the first layer of the surfacing. This normally takes place after 4 weeks.

## **9.8 Important construction details**

### **General**

In addition to normal good construction practice certain construction details require particular attention when constructing sprayed bituminous surfacings, including Otta Seals.

### **Joints**

Extra care is needed at all joints, both horizontal and longitudinal, to ensure that sufficient bitumen is sprayed and sufficient rolling and trafficking is applied. It is necessary to ensure that a minimum longitudinal joint overlap of 150 mm is attained and that additional heavy rolling is applied to even out the joints and the built up ridge caused by bitumen over-spray.

To avoid longitudinal joints it is preferable to spray the full width of the road in one pass if at all possible with the available equipment.

If longitudinal joints are necessary, they should be positioned outside the wheel tracks, i.e. along lane boundaries or the centre line.

Transverse joints should be constructed by normal good sealing techniques whereby start and finishing sheets are used, and the end of the previous section is blinded off to make an accurate starting line for the new section. Any over or under application will cause either a bump, or aggregate stripping respectively. Transverse joints should never be placed on top of each other. These joints should be staggered by approximately 50 metres.

### **Intersections with yield sign, roundabouts and steep gradients**

Due to the relatively soft binder and high binder application rate, heavy trucks may push the seal across the carriageway during the early life of the seal. This can cause ridges of bitumen to be formed, exposing the base in the bottom of the "ruts".

In steep gradients, similar, as for Chip Seal design, the Otta Seal will need adjustment in the binder application rates in steep climbing gradients to prevent excessive bleeding and instability during the early stage of the seal. The same applies at down hill gradients in combination with sharp curves where the vehicles tends to break heavily.

In areas where this may be a problem, one should reduce the binder content by 0,3 l/m<sup>2</sup> and utilise a coarse aggregate grading. In cases where this is regarded to be a major problem, the binder should be 150/200 penetration grade, or if possible a penetration grade slightly harder than 150/200. This can be achieved by adding 2-3 % kerosene (power paraffin or illuminating paraffin) to 80/100 penetration grade bitumen.

# MAINTENANCE

## 10.1 General

As a result of the enhanced durability characteristics of Otta Seals, maintenance intervention is not required to the extent necessary with conventional seals. Thus, such interventions as fog spraying, which is required every 3 - 4 years with Chip Seals, are unnecessary with the Otta Seals. Further, the resealing frequency for the Otta Seal varies between 9 - 15 years, depending on type of seal, whereof for Chip Seals the frequency is in the order of 7 years.

The repair and resealing of any localised surface defects are similar for the Otta Seal as for any other sprayed type of surfacing.

## 10.2 Use of Otta Seals as reseals

The use of Otta Seals as reseals do not differ from other sprayed types of bituminous reseals that are commonly used. The preparatory work necessary for a reseal using a conventional Chip Seal is also required for Otta Seals. However, in contrast to conventional Chip Seals where aggregate size requirements are an important factor depending on the existing seal aggregate, this meshing aggregate requirement does not apply for Otta Seals. Any aggregate size within the general grading envelope can be used.

The Otta Seals are well suited as a reseal for roads that is extensively cracked /patched, but which is still fairly structurally sound. This because of the use of low viscosity binders, high binder content and good interlock between the many particles thick aggregate layer, making the Otta Seal relatively flexible.

The recommended spray rates for Otta reseals are given in Table 8.3b.

# 10



*On pavements that have deteriorated badly, an Otta Seal, because of its durability (high bitumen content and low viscosity binders which make the Otta Seal very flexible) is well suited as a reseal. (Malawi).*

# CONTRACTUAL ISSUES

## 11.1 General

This Chapter deals with some of the important contractual issues which should be considered when specifying Otta Seals, particularly where it contrasts with a conventional Chip Seal. The approach to certain contractual issues differs from normal Chip Seal contracts and the following are considered to be important:

- The need to specify a minimum number of passes with the rolling equipment;
- The requirement for the Otta Seal to be trafficked for a minimum period of 8 - 12 weeks before the second or cover sand seal is applied;
- The back-brooming of dislodged crusher dust/sand to the exposed areas;
- The requirement that road marking cannot be applied until the second seal has settled down, usually several months after the first seal has been applied. There will be a need for temporary road markings in such situations;
- “Bleeding” and blinding of localised areas which may require that a small team must be available to undertake such operations, which may take place during the first hot season after the contract is completed;
- An allowance should be made in the Bill of Quantities for an additional item to clean off blinding sand, in case of extreme bleeding for the first seal, prior to the laying of second or cover seal.

The items listed above may present contractual problems unless they are unambiguously dealt with in the Contract Documents. The following section deals with measures that will cater for these items, which differ from contracts where a conventional Chip Seal is used.

## 11.2 Contractual issues

### *Rolling using pneumatic equipment*

The “Special Technical Provisions” which form a part of the Contract Documents should include the following text:

- Any part of the surfaced area, shoulders included, shall receive not less than 15 passes with a pneumatic tyred roller with a gross weight of not less than 12 tonnes on the day of the sealing operations, and one pass with a static steel roller after the initial roller with the pneumatic roller is completed. In the following two days, further 15 passes with a pneumatic roller will be required on each day.

The Contractor must have sufficient roller capacity on site to achieve the above requirements. In practice, at least 2 pneumatic tyred rollers will be required in addition to the steel roller.

Any other additional rolling will be in accordance with the “payment item for additional passes”.

***The Otta Seal requires to be trafficked for a minimum period of 8 - 12 weeks before the second seal or cover seal is applied.***

This item can cause problems contractually, and may be dealt with as follows:

“Substantial Completion” could be given when the Otta Seal is opened to traffic, provided there are no surface defects or other outstanding works which may violate the “Road Traffic Act” (stop signs, speed limit signs, etc.). It may be necessary to employ temporary road markings for road safety purposes (project dependant).

After a further one month (i.e. approximately 4 months after “Substantial Completion” for the whole contract) the permanent road markings will be painted onto the road surface by the Contractor and the payment for permanent road marking made only at this stage.

***The back-brooming of dislodged aggregates***

A separate pay item for back-brooming of dislodged aggregate should be included in the Contract Documents, possibly as a rate per km.

***Road marking***

The road marking could be undertaken as a separate contract, since a good result is difficult to achieve until a great time after construction (this also applies to a lesser

extent for ordinary Chip Seals). Such practice could be extended to capital as well as maintenance resealing projects.

If it is decided to include road marking in the main contract, then the contractor should be informed of this delay requirement in the contract documents. For safety reasons, some pre-marking or temporary lines may be painted on the road during the interim period.

***Bleeding and blinding off***

Experience within the country has shown that in some cases, especially where the binder application rate is on the high side, some blinding of fatty surface spots may be required during the first hot season after the contract has been completed and the contractor has moved off site. Allowance should be made in the contract for establishment of a team for blinding of the seal, if and when required, for a duration of 4 to 8 weeks.

This item must be included in the Bill of Quantities as a separate item, otherwise, payment may be under Day Works, which will be much more costly. The payment should be specified per km (not per sq. metre).

***Cleaning off blinding sand on the first and second seal***

This should be catered for as an additional pay item in the Contract Documents.

The payment should preferably also be per km.

## THE GLOBAL USE

### 12.1 General

The reported use of Otta Seals can be summarised nine countries: three from northern Europe (Norway, Sweden and Iceland), four in East and Southern Africa (Kenya, Botswana, Zimbabwe and recently also in South Africa) one country in Asia (Bangladesh), and a trial at Victoria State/Territory, Australia.

Figure 12.1 shows the global use of Otta Seals.

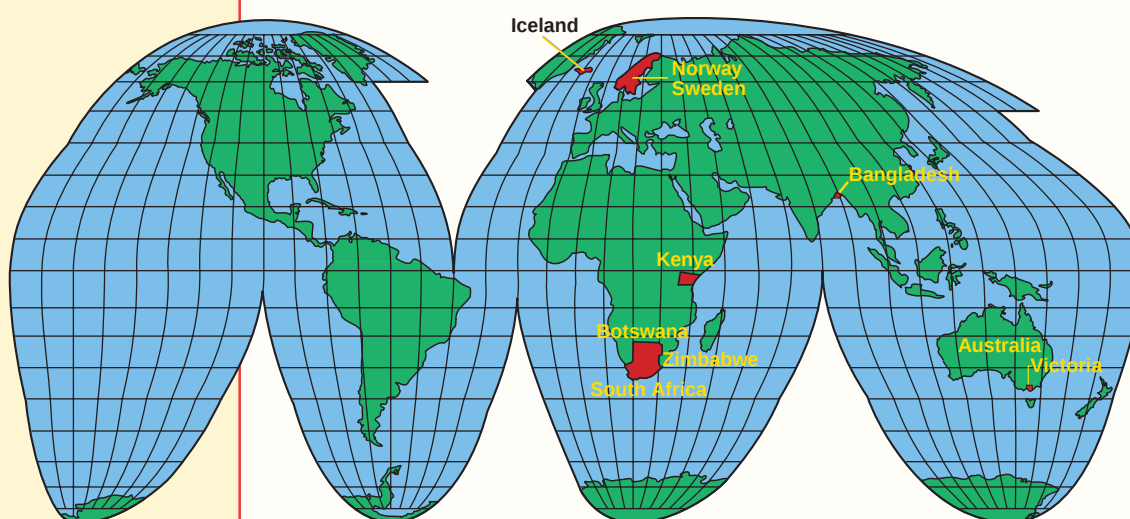


Figure 12.1 The global use of Otta Seals

| Country              | Length            | Comments                                   |
|----------------------|-------------------|--------------------------------------------|
| Norway               | 4000 km           | In 1985 the figure was 12 000 km           |
| Sweden               | 4000 km           |                                            |
| Iceland              | 2000 km +         |                                            |
| Kenya                | 500 km            |                                            |
| Botswana             | 1000 km +         |                                            |
| Zimbabwe             | 80 km             | Inclusive several trials                   |
| South Africa         | One trial, 2 km.  | About 100km to be Otta Sealed in 1999-2000 |
| Bangladesh           | 20 km +           | Only labour based methods used             |
| Australia (Victoria) | Two trial 2,2 km. | 2.2 km in Victoria State/Territory         |

Table 12.1 shows the length of Otta Seals in the various countries, per 1999.

Table 12.1 The global use of Otta Seals.

The use of the Otta Seals have not been as widespread as it could be. The reason for this may be several, but the following may have been the general constraints:

- Firstly - No rational design procedure has been readily available;
- Secondly - The consultants and contractors do not know the Otta Seals application, 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 as per today, although not all, has been done by in-house construction units.

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

## 12.2 Norway

### Background

Service-life and performance depends heavily on local conditions as always, not specifically for the Otta Seal. It is experienced in Norway that on a road with an AADT of about 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 Otta Seal a service life of 5 - 6 years is common.

In total 4000 km are today surfaced by Otta Seals, this counts for about 7% of the total bituminised road network of 52 000 km, whereof 26 000 km comprises of main roads and 26 000 km of secondary roads.

Table 12.2 shows the total length of Single and Double Otta Seals in Norway at the end of 1998.

| Otta Seal type | Type of roads |           |       |
|----------------|---------------|-----------|-------|
|                | Primary       | Secondary | Ratio |
| Single Otta    | 500 km        | 1500 km   | 25/75 |
| Double Otta    | 1000 km       | 1000 km   | 50/50 |

Table 12.2 Total length of Single and Double Otta Seals in Norway at the end of 1998.

In Norway today there are 65 km of Single Otta Seals and 120 km of Double Otta Seals that have been in service for more than 20 years and these roads are still performing satisfactorily. The majority of these roads are part of the secondary road network.

### Norwegian specifications

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

**Traffic** : AADT < 2000

**Aggregates** : Moraine gravel, both screened and crushed or in combination are used. Gabbro is a common rock type used. Experience has shown that a mixture of crushed/uncrushed aggregate ratio of 30/70, respectively, gives the best performance.

Aggregate class - 1 - 3

Flakiness/friability - < 1,5

**Grading** - Requirements in the lower part of the envelope as shown in Table 5.1. Material passing the 4,00mm sieve shall not be less than 35%. Material passing the 0,075mm sieve shall not exceed 10%.

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



Otta Seals have been and is still extensively used in Norway. (Norway).



Otta Seal using crushed aggregate on a primary road after 6 years in service. (Norway).



Close-up of the Otta Seal surfacing. (Norway).

*Bitumen* : Medium curing bitumen, BL 1500M - BL 4500 Emulsion BE 70M, of the following bitumen types MB 3000 - 10 000  
General application rates, BL between 1,7 - 1,9 l/m<sup>2</sup>. BE between 1,9 - 2,1 l/m<sup>2</sup>

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

## 12.3 Sweden

### General

The Otta Seal was introduced in Sweden around 1985. The term for the Otta Seal in Sweden is Y1G and in general their experiences are similar to those from Norway. As per today about 4000 km of roads have been bituminised using Otta Seals. A large proportion of these roads were originally secondary gravel roads in the northern and eastern (forest counties) parts of Sweden that were upgraded to a bituminous standard. The Swedish Road Authority has also used Single Otta Seal as dust binding precautions on gravel roads without any pavement strengthening (life expectancy 3 - 5 years). As quoted from the Swedish Road Authorities (Overby 1997), the general experience by using the Otta Seals has 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 result that the seal has failed much earlier than anticipated.

### Swedish specifications

The general specifications used for Otta Seals (Y1G) are very similar as for those that applies in Norway. However, the maximum AADT is limited to AADT < 500.

## 12.4 Iceland

### General

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 mixing 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 particularly in remote areas.

Per today more than 2000 km have been covered with a double Otta Seal, and the performance is rated to be very good (Overby 1997).

### Iceland specifications

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 requirement is similar to what is given in Tabel 5.1. The strength of the aggregate refers to the LAA value, where the following are adopted in the specifications:

|                 |            |
|-----------------|------------|
| AADT < 200      | LLA < 30%. |
| AADT 200 – 1000 | LLA < 25%  |
| AADT > 1000     | LLA < 20%  |

The most common bitumen used is BL 1500R at an application rate of 2,0 l/m<sup>2</sup>.



A newly laid Otta Seal using crushed basaltic gravel. (Iceland).

## 12.5 Kenya

### General

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 share basis. The project was linked to the new Turkana road in the arid/semi-arid 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 was surfaced using MC 3000 as binder, and alluvial quartzitic gravel screened only (uncrushed) as surfacing aggregate. Aggregate strength was ACV/LAA of 32/49, respectively. The base course thickness was min. 130 mm with the following materials requirements:

- CBR<sub>soaked</sub> nominally min. 50, but single values of 30 were in places accepted.
- PI max. 20.

Benkelman Beam deflection (80 kN) of less than 1,25 mm was regarded as acceptable prior to surfacing (Hansen 1983). No prime was applied on any of the road sections, but an adhesive agent was always admixed in the binder.

### Performance of Otta Seals

A study team (Mariki et al 1995) that visited several of roads in 1995 quoted the following:

#### *Turkana Road at Marich Pass*

The road was completed in 1978 and had in 1995 carried cumulated E 80 loading equal to 4,0 mill. Close to 1 million vehicles had been using the road. Annual mean rainfall is 1000mm.

Part of the section had been resealed (third seal) using Otta Seal with quartzitic gravel similar to what was used for more than 15 years back. Apart from some stone loss the performance was good.

#### *Turkwell Gorge - Lodwar*

This section was completed in 1980. and had in 1995 carried cumulated E 80 loading equal to 2,1 mill. About 700 000 vehicles had been using the road. Annual mean rainfall between 300 - 400 mm.

About half of the road had been resealed using Otta Seal, and its performance was good. Those section that had not been resealed (being in service for more than 17 years without any kind of 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 170 mm was still performing excellent (after 17 years in service) without any sign of potholes or other surfacing defects.

#### *Kalokol – Ferguson's Gulf*

Completed in 1985 and had in 1995 carried cumulated E 80 loading equal to 0,16 million, and about 200 000 vehicles had been using the road. Annual mean rainfall about 170 mm.

Base layer thickness of 70 mm with CBR soaked of 50. Aggregate (0 - 18mm) used 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 was performing extremely well, without any signs of surfacing defects.

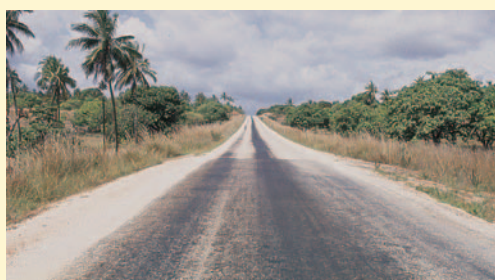


*Turkana road, about 20 km north of Marich Pass. Screened quartzitic gravel were used as aggregate for the Otta Seal. After a number of years in service the performance was good. (Kenya).*

# 12



Close-up of an Otta Seal where natural occurring laterite was used as Otta Seal aggregate. (Kenya).



A section where coral stone was used as Otta Seal aggregate. The first section has been in service for some months and the aggregate has “bed down” making an appealing and uniform appearance. The second section has newly been constructed and the coral aggregate still need some time to “bed down”. After more than 14 years in service these sections are performing excellently. (Kenya).



Under the Rural Roads Programme Otta Seals were extensively used, and in combination with labour based work. Natural decomposed granite used as aggregate for Otta Seal was hand screened and applied by hand. (Botswana).



Overview of the same road (Single Otta Seal) after being in service for more than 8 years. (Botswana).

## **Mombasa, Road trial at Kwale**

The two road sections were constructed in the early 1985. The trial consists of two different types of base material, laterite unstabilised and laterite stabilised with 6% coral fines. Two types of aggregate were used for the Double Otta Seal. Natural occurring laterite with an aggregate strength (ACV/LAA) of 42/54, and where 10% passed the 0,075mm sieve. Oversize material where screened out and crushed.

The crushed coral stone aggregate, where 4% passed the 0,075mm sieve had an aggregate strength (ACV/LAA) of 32/38.

For the conventional Chip Seal a fairly hard crushed sand stone aggregate were used with an aggregate strength of 22/36.

The bitumen used was a MC 3000 viscosity grade, being cut back on site from 80/100 penetration grade bitumen using diesel and kerosine. Application rates 1,8 - 1,9 l/m<sup>2</sup> for both layers of the Otta Seal. For the Chip Seal 80/100 bitumen was used with an application rate of 1,7 and 1,3 l/m<sup>2</sup>, first and second layer, respectively. After 10 years in service the road had carried a cumulated

E 80 loading equal to 0,14 million, and about 900 000 vehicles had been using the road. Annual mean rainfall is 820 mm. All the sections performed excellently. It was however noticed that the Otta Seal had a denser waterproof surface texture than the Chip Seal. The Chip Seal had a more open surface texture and looked “hungry” for bitumen.

## **Road C106, Kwale**

This section was also constructed in 1985 and the traffic loading and rainfall were similar to the previous section. Aggregate for the Double Otta Seal was a mixture of both uncrushed and crushed coral stone aggregate. After 10 years in service the appearance of the surfacing looks more like an asphalt concrete surfacing with a very dense waterproof matrix. A slight “fatty up” was noticed in the wheel paths.

## **Kenyan experience**

The Otta Seals constructed in Kenya since 1978, have been in service between 10 and 17 years under different climatic and traffic conditions. In conclusion, their performance have been excellent, this in despite of the use of inferior aggregates such as uncrushed quartz and laterite gravel, as well as uncrushed/ crushed coral stone.

The use of Otta Seals is included in the Kenyan Road Design Manual of 1987.

## **12.6 Botswana**

### **Rural Roads programme**

In 1974/75 Botswana Roads department started the Rural Roads Programme for construction of gravel roads into the rural areas under the funding by the Norwegian Agency for development Co-operation (NORAD). However, in 1977 it became evident that in the 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 were MC3000 and MC800 applied at a rate between 1,5 and 2,0 l/m<sup>2</sup>.

Application of the binder was carried out by a bitumen distributor while the aggregate was applied by hand.

The Otta Seals showed very satisfying early performance, which triggered off bituminous sealing of several other Rural Roads projects. The variety of aggregate being used were lake gravel deposits consisting of silcrete, quartz and hard nodular calcrete mixed with a small amount of calcareous silt stone, with an ACV of 33 (Overby 1990) crushed soft silcrete and sand stone of very varying quality. These single Otta Seals were always covered by a light spray of binder, MC3000 or MC 800 at an application rate between 0,7 - 0,9 l/m<sup>2</sup>, and covered with Kalahari sand which is easily available over most parts of the country.

## Botswana experience

The Otta Seals have been successfully used in Botswana for the past 20 years. Surfacing using inferior aggregates have performed well for more than 15 years carrying 250-300 vehicles per day. Per today more than 1000 km of roads have been surfaced using a single Otta Seal with a Kalahari sand cover seal on top. This accounts for about 20% of the bituminised road network.

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

In the Botswana Road Design Manual of 1994 the use of Otta Seals is included as an alternative surfacing for Low Volume Roads AADT < 500. However, recently Roads Department has been constructing Otta Seals on roads with much higher traffic volumes. The life expectancy for a Single Otta seal with a sand cover seal on top is 9 - 12 years, and for a Double Otta Seal 12 - 15 years.

## 12.7 Zimbabwe

### Secondary and Feeder Road Development Programme (SFRDP) (Sida and Swerod 1995)

Between 1990 and 1993 a number of test sections were constructed using Otta Seals. Traffic levels varied from about 30 to nearly 300 vehicles per day and the rainfall from less than 300 to more than 1200 mm annually. Materials used were both crushed and uncrushed quarts/granite where materials less than 2,0 mm were screened out. After 4 - 6 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.

## 12.8 Bangladesh

### Environmental Trial Road at Faridpur

Through the Local Government Engineering Department (LGED) Otta Seals were in 1992 constructed as a part of the Environmental Trial Road at Faridpur that aimed at finding a more flexible and durable bituminous surfacing than currently used for Feeder Roads. Common procedure typically consisted of a 25 mm thick bituminous carpeting. Aggregate for the Otta Seal was screened river gravel 0 - 16mm (quartz and basalt) that was placed



Close-up of the previous photo showing a Single Otta Seal. Note that some of the weak aggregate has been crushed down by traffic, but during the early stage after construction the binder has absorbed the crushed aggregate and a dense water-proof surfacing has been formed. (Botswana).



The final product, after 8 months in service of a Single Otta Seal (crushed aggregate) with a sand cover seal on top using fine Kalahari sand. (Botswana).



The same road in a “bird view”. Note the appealing uniform appearance, more like an asphaltic concrete. (Botswana).



At the Environmental trial Road at Faridpur, the bitumen was both cutback and fluxed in order to give the correct binder consistence. This was successfully carried out by simple but appropriate methods. (Bangladesh).

# 12



*The Otta Seal aggregate was applied by labour based methods, by pre-stockpiling the hand crushed aggregate. A 100 metre long section, 3,7 metres wide was covered by aggregate after 7 minutes time, and the section was opened to traffic. (Bangladesh).*



*In the absence of pneumatic tired rollers, rolling of the Otta Seal can be done by loaded trucks following a pre-determined pattern of rolling. (Bangladesh).*



*The final product, a Single Otta Seal after 2 years in service. (Bangladesh).*



*Otta Seals trial, using crushed quartzite with a high amount of fines. The aggregate was applied by a self-propelled chip spreader. (South Africa).*

along the road side in small stockpiles and applied immediately by hand after the binder was sprayed. The binder, 80/100 pen. grade, arrived in drums that were pre-heated and emptied into a tractor-pulled distributor.

By addition of cutters (paraffin) the binder was altered to satisfy the requirements for viscosity during construction. Flux (engine oil) was added to improve the long term durability of the binder.

The binder application rates varied between 1,9 - 2,1 l/m<sup>2</sup>. Half-loaded trucks carried out the rolling by trafficking in a predetermined rolling pattern. Neither prime nor adhesion additives were used.

## **Bangladesh experience**

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

Also from a construction point of view the Otta Seal has advantages under conditions as in a country as Bangladesh. On feeder roads detours are difficult, or in many cases impossible, to construct due to narrow crone and high embankments. It is important that the road is not closed to traffic over a long period, normally maximum one hour. The Otta Seal construction allows for trafficking immediately after spreading the aggregate, while Chip Seals or asphalt carpets need a primed base to perform satisfactorily. Priming under these conditions would require closing of the road for several hours, and in addition blinding off the prime with sand would in most cases be required.

The Labour Based methods extensively used in Bangladesh have also proved to favour the use of Otta Seals, as a large proportion of the work can be done by labours.

Per today, about 20 km of roads have been surfaced using labour intensive methods and Otta Seals. A Sprayed Sealing Guideline for Otta Seals in Bangladesh has been prepared and its specifications form a part of the LGED Standard Specifications.

## **12.9 South Africa**

### **Trial sections**

In KwaZulu Natal province in South Africa the first Otta Seal surfacing trial took place in June 1999. Two types of aggregate were used:

- decomposed granite with low aggregate strength
- crushed quartzite with high aggregate strength (10% FACT = 200), but with high fines content (more than 10% passing the 0,075 mm sieve)

The binder was 150/200 penetration grade bitumen, cut back on site by power paraffin to the required viscosity range. The hot bitumen spray rates varied between 1,7 - 2,2 l/m<sup>2</sup> depending on the aggregate grading and whether the base was primed or un-primed. The traffic volume was between 300 - 500 vehicles per day.

During the trial the Road Authorities stated that the aggregate used in the Otta Seal would under no circumstances be considered used in a bituminous surfacing in the province. The early performance of the Otta Seals is very promising and would imply a considerable user cost saving in upgrading the gravel road to a bituminous standard.

The KwaZulu, Natal Road Authorities plans to embark on a full scale project in October 1999 to upgrade about 100 km of gravel roads to bituminous standard using Otta Seals.

## 12.10 Australia

In early 1999 a small trial using Otta Seals were constructed at Victoria State/Territory, using crushed aggregates with fines content passing the 0.075 mm sieve restricted to 10%. The base was not primed and a Single Otta Seal was applied. After 7 months in service the surface shows no sign of premature deterioration. The traffic level on the access road is low but used by heavy load trucks moving in and out from a quarry side.

A full scale Otta Seal trial at the length of 2 km was undertaken in June 1999 using cutback bitumen and aggregate confirming the recommended grading curve. The AADT on this rural road is about 100. The Victoria State/Territory plan to construct more Otta Seal in the near future.

## 12.11 Historical summary

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 surface treatment with no other limitations regarding traffic than one would apply to any other sprayed bituminous surfacing.

The Otta Seal method 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 in northern Europe to tropical hot/wet climate as experienced in Asia and desert dry and very hot climatic conditions prevailing on the east and southern part of the African continent.

The Otta Seal has proved to be a durable and a very cost-effective surfacing. 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 to make life-cost comparisons to other sprayed bituminous surfacing, assessing the availability of local materials and their use in an Otta Seal when considering appropriate surfacing for roads (low volume roads) carrying traffic volumes of less than 1000 vpd. This exercise may in many cases conclude that Otta Seals is the most economical and appropriate surfacing type.

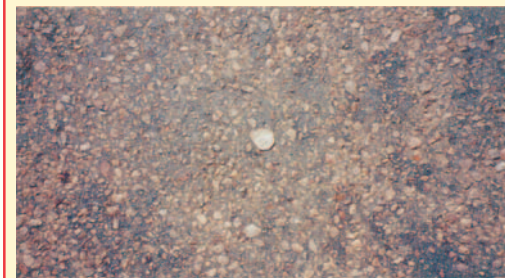
The Otta Seal has repeatedly proven to be a very forgiving type of sprayed seal under quite different environments. Poor workmanship etc. during construction, that would have been disastrous in the case of a Chip Seal, will in many incidents give satisfactory performance in the case of Otta Seals.



*Immediately after the Otta Seal aggregate has been applied. The seal looks like a gravel road at this stage. But with time, the single Otta Seal will "bed down" and a bit premix type appearance will appear. (South Africa).*



*The same road as above, but after 3 months in service. (South Africa).*



*Close up of the Single Otta Seal above. Note the close surface texture, making an impermeable surfacing. (South Africa).*

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# APPENDIX A

## Mass/Volume conversion Tables

### MEXPHALTE 80/100

| MASS<br>(kg) | VOLUME (litres) at TEMPERATURE (°C) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|--------------|-------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|              | 20                                  | 100   | 105   | 110   | 115   | 120   | 125   | 130   | 135   | 140   | 145   | 150   | 155   | 160   | 165   | 170   | 175   | 180   | 185   | 190   |
| 10           | 10                                  | 10    | 10    | 10    | 10    | 10    | 10    | 10    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    |
| 20           | 20                                  | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 22    | 22    | 22    | 22    | 22    |
| 30           | 29                                  | 31    | 31    | 31    | 31    | 31    | 31    | 31    | 32    | 32    | 32    | 32    | 32    | 32    | 32    | 32    | 32    | 33    | 33    | 33    |
| 40           | 39                                  | 41    | 41    | 41    | 42    | 42    | 42    | 42    | 42    | 42    | 42    | 43    | 43    | 43    | 43    | 43    | 43    | 43    | 43    | 44    |
| 50           | 49                                  | 51    | 52    | 52    | 52    | 52    | 52    | 52    | 53    | 53    | 53    | 53    | 53    | 53    | 54    | 54    | 54    | 54    | 54    | 55    |
| 60           | 59                                  | 62    | 62    | 62    | 62    | 63    | 63    | 63    | 63    | 63    | 64    | 64    | 64    | 64    | 64    | 65    | 65    | 65    | 65    | 66    |
| 70           | 68                                  | 72    | 72    | 73    | 73    | 73    | 73    | 73    | 74    | 74    | 74    | 74    | 75    | 75    | 75    | 75    | 76    | 76    | 76    | 77    |
| 80           | 78                                  | 82    | 83    | 83    | 83    | 83    | 84    | 84    | 84    | 84    | 85    | 85    | 85    | 86    | 86    | 86    | 86    | 87    | 87    | 88    |
| 90           | 88                                  | 93    | 93    | 93    | 94    | 94    | 94    | 94    | 95    | 95    | 95    | 96    | 96    | 96    | 97    | 97    | 97    | 98    | 98    | 99    |
| 100          | 98                                  | 103   | 103   | 104   | 104   | 104   | 105   | 105   | 105   | 106   | 106   | 106   | 107   | 107   | 107   | 108   | 108   | 108   | 109   | 109   |
| 200          | 196                                 | 206   | 207   | 207   | 208   | 209   | 209   | 210   | 211   | 211   | 212   | 213   | 213   | 214   | 215   | 215   | 216   | 217   | 217   | 219   |
| 300          | 294                                 | 309   | 310   | 311   | 312   | 313   | 314   | 315   | 316   | 317   | 318   | 319   | 320   | 321   | 322   | 323   | 324   | 325   | 326   | 328   |
| 400          | 391                                 | 412   | 413   | 414   | 416   | 417   | 418   | 420   | 421   | 422   | 424   | 425   | 426   | 428   | 429   | 431   | 432   | 433   | 435   | 438   |
| 500          | 489                                 | 515   | 516   | 518   | 520   | 521   | 523   | 525   | 526   | 528   | 530   | 531   | 533   | 535   | 537   | 538   | 540   | 542   | 543   | 547   |
| 600          | 587                                 | 618   | 620   | 622   | 623   | 626   | 627   | 630   | 632   | 634   | 636   | 638   | 640   | 642   | 644   | 646   | 648   | 650   | 652   | 657   |
| 700          | 685                                 | 721   | 723   | 725   | 727   | 730   | 732   | 734   | 737   | 739   | 742   | 744   | 746   | 749   | 751   | 754   | 756   | 758   | 761   | 766   |
| 800          | 783                                 | 823   | 826   | 829   | 831   | 834   | 837   | 839   | 842   | 845   | 848   | 850   | 853   | 856   | 858   | 861   | 864   | 867   | 870   | 876   |
| 900          | 881                                 | 926   | 929   | 932   | 935   | 938   | 941   | 944   | 947   | 950   | 953   | 956   | 960   | 963   | 966   | 969   | 972   | 975   | 978   | 985   |
| 1 000        | 978                                 | 1 029 | 1 033 | 1 036 | 1 039 | 1 043 | 1 046 | 1 049 | 1 053 | 1 056 | 1 059 | 1 063 | 1 066 | 1 070 | 1 073 | 1 077 | 1 080 | 1 083 | 1 087 | 1 095 |
| 2 000        | 1 957                               | 2 059 | 2 065 | 2 072 | 2 078 | 2 085 | 2 092 | 2 098 | 2 105 | 2 112 | 2 119 | 2 125 | 2 132 | 2 139 | 2 146 | 2 153 | 2 160 | 2 167 | 2 174 | 2 190 |
| 3 000        | 2 935                               | 3 088 | 3 098 | 3 108 | 3 117 | 3 128 | 3 137 | 3 148 | 3 158 | 3 168 | 3 178 | 3 188 | 3 199 | 3 209 | 3 219 | 3 230 | 3 240 | 3 250 | 3 261 | 3 285 |
| 4 000        | 3 914                               | 4 117 | 4 130 | 4 143 | 4 157 | 4 170 | 4 183 | 4 197 | 4 210 | 4 224 | 4 238 | 4 251 | 4 265 | 4 278 | 4 292 | 4 306 | 4 320 | 4 334 | 4 348 | 4 379 |
| 5 000        | 4 892                               | 5 147 | 5 163 | 5 179 | 5 196 | 5 213 | 5 229 | 5 246 | 5 263 | 5 280 | 5 297 | 5 314 | 5 331 | 5 348 | 5 366 | 5 383 | 5 400 | 5 417 | 5 435 | 5 474 |

### MEXPHALTE 80/100

| MASS<br>(kg) | VOLUME (litres) at TEMPERATURE (°C) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
|--------------|-------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|              | 20                                  | 100    | 105    | 110    | 115    | 120    | 125    | 130    | 135    | 140    | 145    | 150    | 155    | 160    | 165    | 170    | 175    | 180    | 185    | 190    |
| 6 000        | 5 871                               | 6 176  | 6 195  | 6 215  | 6 235  | 6 256  | 6 275  | 6 295  | 6 315  | 6 336  | 6 356  | 6 376  | 6 397  | 6 418  | 6 439  | 6 459  | 6 480  | 6 501  | 6 522  | 6 569  |
| 7 000        | 6 849                               | 7 205  | 7 228  | 7 251  | 7 274  | 7 298  | 7 321  | 7 344  | 7 368  | 7 392  | 7 416  | 7 439  | 7 464  | 7 487  | 7 512  | 7 536  | 7 560  | 7 584  | 7 609  | 7 664  |
| 8 000        | 7 828                               | 8 235  | 8 261  | 8 287  | 8 313  | 8 341  | 8 367  | 8 394  | 8 421  | 8 448  | 8 475  | 8 502  | 8 530  | 8 557  | 8 585  | 8 612  | 8 640  | 8 668  | 8 696  | 8 759  |
| 9 000        | 8 806                               | 9 264  | 9 293  | 9 323  | 9 352  | 9 383  | 9 412  | 9 443  | 9 473  | 9 504  | 9 535  | 9 565  | 9 596  | 9 626  | 9 658  | 9 689  | 9 720  | 9 751  | 9 783  | 9 854  |
| 10 000       | 9 785                               | 10 293 | 10 326 | 10 359 | 10 392 | 10 426 | 10 458 | 10 492 | 10 526 | 10 560 | 10 594 | 10 627 | 10 662 | 10 696 | 10 731 | 10 765 | 10 800 | 10 835 | 10 870 | 10 949 |
| 11 000       | 10 763                              | 11 323 | 11 358 | 11 394 | 11 431 | 11 469 | 11 504 | 11 541 | 11 578 | 11 616 | 11 654 | 11 690 | 11 728 | 11 766 | 11 804 | 11 842 | 11 880 | 11 918 | 11 956 | 12 043 |
| 12 000       | 11 742                              | 12 352 | 12 391 | 12 430 | 12 470 | 12 511 | 12 550 | 12 590 | 12 631 | 12 672 | 12 713 | 12 753 | 12 795 | 12 835 | 12 877 | 12 919 | 12 960 | 13 002 | 13 043 | 13 138 |
| 13 000       | 12 720                              | 13 381 | 13 424 | 13 466 | 13 509 | 13 554 | 13 596 | 13 639 | 13 683 | 13 728 | 13 772 | 13 816 | 13 861 | 13 905 | 13 951 | 13 995 | 14 040 | 14 085 | 14 130 | 14 233 |
| 14 000       | 13 699                              | 14 411 | 14 456 | 14 502 | 14 548 | 14 596 | 14 642 | 14 689 | 14 736 | 14 784 | 14 832 | 14 878 | 14 927 | 14 974 | 15 024 | 15 072 | 15 120 | 15 168 | 15 217 | 15 328 |
| 15 000       | 14 677                              | 15 440 | 15 489 | 15 538 | 15 587 | 15 639 | 15 687 | 15 738 | 15 789 | 15 840 | 15 891 | 15 941 | 15 993 | 16 044 | 16 097 | 16 148 | 16 200 | 16 252 | 16 304 | 16 423 |
| 16 000       | 15 656                              | 16 469 | 16 521 | 16 574 | 16 627 | 16 681 | 16 733 | 16 787 | 16 841 | 16 896 | 16 951 | 17 004 | 17 060 | 17 114 | 17 170 | 17 225 | 17 280 | 17 335 | 17 391 | 17 518 |
| 17 000       | 16 634                              | 17 498 | 17 554 | 17 610 | 17 666 | 17 724 | 17 779 | 17 836 | 17 894 | 17 952 | 18 010 | 18 067 | 18 126 | 18 183 | 18 243 | 18 301 | 18 360 | 18 419 | 18 478 | 18 613 |
| 18 000       | 17 613                              | 18 528 | 18 586 | 18 645 | 18 705 | 18 767 | 18 825 | 18 885 | 18 946 | 19 008 | 19 069 | 19 129 | 19 192 | 19 253 | 19 316 | 19 378 | 19 440 | 19 502 | 19 565 | 19 707 |
| 19 000       | 18 591                              | 19 557 | 19 619 | 19 681 | 19 744 | 19 809 | 19 871 | 19 935 | 19 999 | 20 064 | 20 129 | 20 192 | 20 258 | 20 322 | 20 389 | 20 454 | 20 520 | 20 586 | 20 652 | 20 802 |
| 20 000       | 19 569                              | 20 586 | 20 652 | 20 717 | 20 783 | 20 852 | 20 916 | 20 984 | 21 051 | 21 120 | 21 188 | 21 255 | 21 324 | 21 392 | 21 462 | 21 531 | 21 600 | 21 669 | 21 739 | 21 897 |
| 21 000       | 20 548                              | 21 616 | 21 684 | 21 753 | 21 822 | 21 894 | 21 962 | 22 033 | 22 104 | 22 176 | 22 248 | 22 318 | 22 391 | 22 462 | 22 536 | 22 607 | 22 680 | 22 753 | 22 826 | 22 992 |
| 22 000       | 21 526                              | 22 645 | 22 717 | 22 789 | 22 862 | 22 937 | 23 008 | 23 082 | 23 157 | 23 232 | 23 307 | 23 380 | 23 457 | 23 531 | 23 609 | 23 684 | 23 760 | 23 836 | 23 913 | 24 087 |
| 23 000       | 22 505                              | 23 674 | 23 749 | 23 825 | 23 901 | 23 980 | 24 054 | 24 131 | 24 209 | 24 288 | 24 366 | 24 443 | 24 523 | 24 601 | 24 682 | 24 761 | 24 840 | 24 920 | 25 000 | 25 182 |
| 24 000       | 23 483                              | 24 704 | 24 782 | 24 861 | 24 940 | 25 022 | 25 100 | 25 181 | 25 262 | 25 344 | 25 426 | 25 506 | 25 589 | 25 670 | 25 755 | 25 837 | 25 920 | 26 003 | 26 087 | 26 277 |
| 25 000       | 24 462                              | 25 733 | 25 815 | 25 897 | 25 979 | 26 065 | 26 146 | 26 230 | 26 314 | 26 400 | 26 485 | 26 569 | 26 656 | 26 740 | 26 828 | 26 914 | 27 000 | 27 087 | 27 174 | 27 371 |

**SPRAMEX 150/200**

| MASS<br>(kg) | VOLUME (litres) at TEMPERATURE (°C) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|--------------|-------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|              | 20                                  | 90    | 95    | 100   | 105   | 110   | 115   | 120   | 125   | 130   | 135   | 140   | 145   | 150   | 155   | 160   | 165   | 170   | 175   | 180   |
| 10           | 10                                  | 10    | 10    | 10    | 10    | 10    | 10    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    |
| 20           | 20                                  | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 22    | 22    | 22    | 22    | 22    | 22    |
| 30           | 30                                  | 31    | 31    | 31    | 31    | 31    | 31    | 32    | 32    | 32    | 32    | 32    | 32    | 32    | 32    | 32    | 32    | 33    | 33    | 33    |
| 40           | 39                                  | 41    | 41    | 42    | 42    | 42    | 42    | 42    | 42    | 42    | 42    | 43    | 43    | 43    | 43    | 43    | 43    | 43    | 44    | 44    |
| 50           | 49                                  | 52    | 52    | 52    | 52    | 52    | 52    | 53    | 53    | 53    | 53    | 53    | 53    | 54    | 54    | 54    | 54    | 54    | 54    | 55    |
| 60           | 59                                  | 62    | 62    | 62    | 63    | 63    | 63    | 63    | 63    | 64    | 64    | 64    | 64    | 64    | 65    | 65    | 65    | 65    | 65    | 66    |
| 70           | 69                                  | 72    | 72    | 73    | 73    | 73    | 73    | 74    | 74    | 74    | 74    | 75    | 75    | 75    | 75    | 76    | 76    | 76    | 76    | 77    |
| 80           | 79                                  | 83    | 83    | 83    | 83    | 84    | 84    | 84    | 84    | 85    | 85    | 85    | 86    | 86    | 86    | 86    | 87    | 87    | 87    | 87    |
| 90           | 89                                  | 93    | 93    | 93    | 94    | 94    | 94    | 95    | 95    | 95    | 96    | 96    | 96    | 96    | 97    | 97    | 97    | 98    | 98    | 98    |
| 100          | 99                                  | 103   | 104   | 104   | 104   | 105   | 105   | 105   | 106   | 106   | 106   | 107   | 107   | 107   | 108   | 108   | 108   | 109   | 109   | 109   |
| 200          | 197                                 | 206   | 207   | 208   | 208   | 209   | 210   | 210   | 211   | 212   | 212   | 213   | 214   | 214   | 215   | 216   | 217   | 217   | 218   | 219   |
| 300          | 296                                 | 310   | 311   | 312   | 313   | 314   | 315   | 316   | 317   | 318   | 319   | 320   | 321   | 322   | 323   | 324   | 325   | 326   | 327   | 328   |
| 400          | 395                                 | 413   | 414   | 415   | 417   | 418   | 419   | 421   | 422   | 423   | 425   | 426   | 428   | 429   | 430   | 432   | 433   | 434   | 436   | 437   |
| 500          | 494                                 | 516   | 518   | 519   | 521   | 523   | 524   | 526   | 528   | 529   | 531   | 533   | 534   | 536   | 538   | 540   | 541   | 543   | 545   | 547   |
| 600          | 592                                 | 619   | 621   | 623   | 625   | 627   | 629   | 631   | 633   | 635   | 637   | 639   | 641   | 643   | 645   | 647   | 650   | 652   | 654   | 656   |
| 700          | 691                                 | 722   | 725   | 727   | 729   | 732   | 734   | 736   | 739   | 741   | 743   | 746   | 748   | 751   | 753   | 755   | 758   | 760   | 763   | 765   |
| 800          | 790                                 | 825   | 828   | 831   | 833   | 836   | 839   | 841   | 844   | 847   | 850   | 852   | 855   | 858   | 861   | 863   | 866   | 869   | 872   | 874   |
| 900          | 888                                 | 929   | 932   | 935   | 938   | 941   | 944   | 947   | 950   | 953   | 956   | 959   | 962   | 965   | 968   | 971   | 974   | 978   | 981   | 984   |
| 1 000        | 987                                 | 1 032 | 1 035 | 1 038 | 1 042 | 1 045 | 1 048 | 1 052 | 1 055 | 1 059 | 1 062 | 1 065 | 1 069 | 1 072 | 1 076 | 1 079 | 1 083 | 1 086 | 1 090 | 1 093 |
| 2 000        | 1 974                               | 2 064 | 2 070 | 2 077 | 2 084 | 2 090 | 2 097 | 2 104 | 2 110 | 2 117 | 2 124 | 2 131 | 2 138 | 2 144 | 2 151 | 2 158 | 2 165 | 2 172 | 2 179 | 2 186 |
| 3 000        | 2 962                               | 3 096 | 3 106 | 3 115 | 3 125 | 3 135 | 3 145 | 3 156 | 3 165 | 3 176 | 3 186 | 3 196 | 3 206 | 3 217 | 3 227 | 3 237 | 3 248 | 3 258 | 3 269 | 3 279 |
| 4 000        | 3 949                               | 4 127 | 4 141 | 4 154 | 4 167 | 4 180 | 4 194 | 4 207 | 4 220 | 4 234 | 4 248 | 4 261 | 4 275 | 4 289 | 4 303 | 4 316 | 4 331 | 4 344 | 4 358 | 4 372 |
| 5 000        | 4 936                               | 5 159 | 5 176 | 5 192 | 5 209 | 5 225 | 5 242 | 5 259 | 5 276 | 5 293 | 5 310 | 5 327 | 5 344 | 5 361 | 5 378 | 5 396 | 5 413 | 5 431 | 5 448 | 5 465 |

**SPRAMEX 150/200**

| MASS<br>(kg) | VOLUME (litres) at TEMPERATURE (°C) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
|--------------|-------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|              | 20                                  | 90     | 95     | 100    | 105    | 110    | 115    | 120    | 125    | 130    | 135    | 140    | 145    | 150    | 155    | 160    | 165    | 170    | 175    | 180    |
| 6 000        | 5923                                | 6 191  | 6 211  | 6 231  | 6 251  | 6 270  | 6 290  | 6 311  | 6 331  | 6 351  | 6 372  | 6 392  | 6 413  | 6 433  | 6 454  | 6 475  | 6 496  | 6 517  | 6 538  | 6 559  |
| 7 000        | 6 910                               | 7 223  | 7 246  | 7 269  | 7 292  | 7 315  | 7 339  | 7 363  | 7 386  | 7 410  | 7 433  | 7 458  | 7 482  | 7 505  | 7 530  | 7 554  | 7 579  | 7 603  | 7 627  | 7 652  |
| 8 000        | 7 897                               | 8 255  | 8 282  | 8 308  | 8 334  | 8 361  | 8 387  | 8 415  | 8 441  | 8 468  | 8 495  | 8 523  | 8 551  | 8 578  | 8 606  | 8 633  | 8 661  | 8 689  | 8 717  | 8 745  |
| 9 000        | 8 885                               | 9 287  | 9 317  | 9 346  | 9 376  | 9 406  | 9 436  | 9 467  | 9 496  | 9 527  | 9 557  | 9 588  | 9 619  | 9 650  | 9 681  | 9 712  | 9 744  | 9 775  | 9 806  | 9 838  |
| 10 000       | 9 872                               | 10 318 | 10 352 | 10 385 | 10 418 | 10 451 | 10 484 | 10 519 | 10 551 | 10 585 | 10 619 | 10 654 | 10 688 | 10 722 | 10 757 | 10 791 | 10 827 | 10 861 | 10 896 | 10 931 |
| 11 000       | 10 859                              | 11 350 | 11 387 | 11 423 | 11 459 | 11 496 | 11 532 | 11 570 | 11 606 | 11 644 | 11 681 | 11 719 | 11 757 | 11 794 | 11 833 | 11 870 | 11 909 | 11 947 | 11 985 | 12 024 |
| 12 000       | 11 846                              | 12 382 | 12 422 | 12 462 | 12 501 | 12 541 | 12 581 | 12 622 | 12 661 | 12 702 | 12 743 | 12 784 | 12 826 | 12 866 | 12 908 | 12 949 | 12 992 | 13 033 | 13 075 | 13 117 |
| 13 000       | 12 833                              | 13 414 | 13 458 | 13 500 | 13 543 | 13 586 | 13 629 | 13 674 | 13 717 | 13 761 | 13 805 | 13 850 | 13 895 | 13 938 | 13 984 | 14 028 | 14 075 | 14 119 | 14 165 | 14 210 |
| 14 000       | 13 820                              | 14 446 | 14 493 | 14 539 | 14 585 | 14 631 | 14 678 | 14 726 | 14 772 | 14 819 | 14 867 | 14 915 | 14 964 | 15 011 | 15 060 | 15 107 | 15 157 | 15 206 | 15 254 | 15 303 |
| 15 000       | 14 808                              | 15 478 | 15 528 | 15 577 | 15 626 | 15 676 | 15 726 | 15 778 | 15 827 | 15 878 | 15 929 | 15 980 | 16 032 | 16 083 | 16 135 | 16 187 | 16 240 | 16 292 | 16 344 | 16 396 |
| 16 000       | 15 795                              | 16 510 | 16 563 | 16 615 | 16 668 | 16 721 | 16 774 | 16 830 | 16 882 | 16 936 | 16 991 | 17 046 | 17 101 | 17 155 | 17 211 | 17 266 | 17 323 | 17 378 | 17 433 | 17 489 |
| 17 000       | 16 782                              | 17 541 | 17 598 | 17 654 | 17 710 | 17 766 | 17 823 | 17 882 | 17 937 | 17 995 | 18 053 | 18 111 | 18 170 | 18 227 | 18 287 | 18 345 | 18 405 | 18 464 | 18 523 | 18 582 |
| 18 000       | 17 769                              | 18 573 | 18 634 | 18 692 | 18 752 | 18 811 | 18 871 | 18 933 | 18 992 | 19 053 | 19 115 | 19 177 | 19 239 | 19 299 | 19 363 | 19 424 | 19 488 | 19 550 | 19 613 | 19 676 |
| 19 000       | 18 756                              | 19 605 | 19 669 | 19 731 | 19 793 | 19 856 | 19 919 | 19 985 | 20 047 | 20 112 | 20 177 | 20 242 | 20 308 | 20 372 | 20 438 | 20 503 | 20 570 | 20 636 | 20 702 | 20 769 |
| 20 000       | 19 743                              | 20 637 | 20 704 | 20 769 | 20 835 | 20 901 | 20 968 | 21 037 | 21 102 | 21 170 | 21 239 | 21 307 | 21 377 | 21 444 | 21 514 | 21 582 | 21 653 | 21 722 | 21 792 | 21 862 |
| 21 000       | 20 731                              | 21 669 | 21 739 | 21 808 | 21 877 | 21 946 | 22 016 | 22 089 | 22 157 | 22 229 | 22 300 | 22 373 | 22 445 | 22 516 | 22 590 | 22 661 | 22 736 | 22 808 | 22 881 | 22 955 |
| 22 000       | 21 718                              | 22 701 | 22 774 | 22 846 | 22 919 | 22 991 | 23 065 | 23 141 | 23 213 | 23 287 | 23 362 | 23 438 | 23 514 | 23 588 | 23 665 | 23 740 | 23 818 | 23 894 | 23 971 | 24 048 |
| 23 000       | 22 705                              | 23 732 | 23 810 | 23 885 | 23 960 | 24 036 | 24 113 | 24 193 | 24 268 | 24 346 | 24 424 | 24 503 | 24 583 | 24 660 | 24 741 | 24 819 | 24 901 | 24 981 | 25 061 | 25 141 |
| 24 000       | 23 692                              | 24 764 | 24 845 | 24 923 | 25 002 | 25 082 | 25 161 | 25 245 | 25 323 | 25 404 | 25 486 | 25 569 | 25 652 | 25 733 | 25 817 | 25 899 | 25 984 | 26 067 | 26 150 | 26 234 |
| 25 000       | 24 679                              | 25 796 | 25 880 | 25 962 | 26 044 | 26 127 | 26 210 | 26 296 | 26 378 | 26 463 | 26 548 | 26 634 | 26 721 | 26 805 | 26 892 | 26 978 | 27 066 | 27 153 | 27 240 | 27 327 |

# SHELMAC MC-800

| MASS<br>(kg) | VOLUME (litres) at TEMPERATURE (°C) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|--------------|-------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|              | 20                                  | 55    | 60    | 65    | 70    | 75    | 80    | 85    | 90    | 95    | 100   | 105   | 110   | 115   | 120   | 125   | 130   | 135   |
| 10           | 10                                  | 10    | 10    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    | 11    |
| 20           | 20                                  | 21    | 21    | 21    | 21    | 21    | 21    | 21    | 22    | 22    | 22    | 22    | 22    | 22    | 22    | 22    | 22    | 22    |
| 30           | 31                                  | 31    | 31    | 32    | 32    | 32    | 32    | 32    | 32    | 32    | 32    | 32    | 33    | 33    | 33    | 33    | 33    | 33    |
| 40           | 41                                  | 42    | 42    | 42    | 42    | 43    | 43    | 43    | 43    | 43    | 43    | 43    | 44    | 44    | 44    | 44    | 44    | 44    |
| 50           | 51                                  | 52    | 52    | 53    | 53    | 53    | 53    | 54    | 54    | 54    | 54    | 54    | 55    | 55    | 55    | 55    | 55    | 56    |
| 60           | 61                                  | 63    | 63    | 63    | 64    | 64    | 64    | 64    | 65    | 65    | 65    | 65    | 65    | 66    | 66    | 66    | 66    | 67    |
| 70           | 72                                  | 73    | 73    | 74    | 74    | 74    | 75    | 75    | 75    | 76    | 76    | 76    | 76    | 77    | 77    | 77    | 77    | 78    |
| 80           | 82                                  | 84    | 84    | 84    | 85    | 85    | 85    | 86    | 86    | 86    | 87    | 87    | 87    | 88    | 88    | 88    | 89    | 89    |
| 90           | 92                                  | 94    | 94    | 95    | 95    | 96    | 96    | 96    | 97    | 97    | 97    | 98    | 98    | 99    | 99    | 99    | 100   | 100   |
| 100          | 102                                 | 105   | 105   | 106   | 106   | 106   | 107   | 107   | 108   | 108   | 108   | 109   | 109   | 109   | 110   | 110   | 111   | 111   |
| 200          | 204                                 | 209   | 210   | 211   | 212   | 213   | 214   | 214   | 215   | 216   | 217   | 217   | 218   | 219   | 220   | 221   | 221   | 222   |
| 300          | 307                                 | 314   | 315   | 317   | 318   | 319   | 320   | 321   | 323   | 324   | 325   | 326   | 327   | 328   | 330   | 331   | 332   | 333   |
| 400          | 409                                 | 418   | 419   | 422   | 424   | 426   | 427   | 429   | 430   | 432   | 433   | 435   | 436   | 438   | 440   | 441   | 443   | 444   |
| 500          | 511                                 | 523   | 524   | 528   | 530   | 532   | 534   | 536   | 538   | 540   | 542   | 543   | 545   | 547   | 549   | 551   | 553   | 555   |
| 600          | 613                                 | 627   | 629   | 634   | 636   | 638   | 641   | 643   | 645   | 647   | 650   | 652   | 655   | 657   | 659   | 662   | 664   | 666   |
| 700          | 716                                 | 732   | 734   | 739   | 742   | 745   | 747   | 750   | 753   | 755   | 758   | 761   | 764   | 766   | 769   | 772   | 775   | 778   |
| 800          | 818                                 | 836   | 839   | 845   | 848   | 851   | 854   | 857   | 860   | 863   | 866   | 870   | 873   | 876   | 879   | 882   | 885   | 889   |
| 900          | 920                                 | 941   | 944   | 950   | 954   | 957   | 961   | 964   | 968   | 971   | 975   | 978   | 982   | 985   | 989   | 992   | 996   | 1 000 |
| 1 000        | 1 022                               | 1 045 | 1 049 | 1 056 | 1 060 | 1 064 | 1 068 | 1 071 | 1 075 | 1 079 | 1 083 | 1 087 | 1 091 | 1 095 | 1 099 | 1 103 | 1 107 | 1 111 |
| 2 000        | 2 045                               | 2 091 | 2 097 | 2 112 | 2 120 | 2 128 | 2 135 | 2 143 | 2 151 | 2 158 | 2 166 | 2 174 | 2 182 | 2 190 | 2 198 | 2 206 | 2 214 | 2 222 |
| 3 000        | 3 067                               | 3 136 | 3 146 | 3 168 | 3 180 | 3 191 | 3 203 | 3 214 | 3 226 | 3 237 | 3 249 | 3 261 | 3 273 | 3 285 | 3 297 | 3 308 | 3 321 | 3 332 |
| 4 000        | 4 090                               | 4 181 | 4 194 | 4 224 | 4 240 | 4 255 | 4 270 | 4 286 | 4 301 | 4 317 | 4 332 | 4 348 | 4 364 | 4 379 | 4 395 | 4 411 | 4 427 | 4 443 |
| 5 000        | 5 112                               | 5 226 | 5 243 | 5 280 | 5 300 | 5 319 | 5 338 | 5 357 | 5 376 | 5 396 | 5 415 | 5 435 | 5 454 | 5 474 | 5 494 | 5 514 | 5 534 | 5 554 |

# SHELMAC MC-800

| MASS<br>(kg) | VOLUME (litres) at TEMPERATURE (°C) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
|--------------|-------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|              | 20                                  | 55     | 60     | 65     | 70     | 75     | 80     | 85     | 90     | 95     | 100    | 105    | 110    | 115    | 120    | 125    | 130    | 135    |
| 6 000        | 6 135                               | 6 272  | 6 292  | 6 336  | 6 359  | 6 383  | 6 405  | 6 429  | 6 452  | 6 475  | 6 498  | 6 522  | 6 545  | 6 569  | 6 593  | 6 617  | 6 641  | 6 665  |
| 7 000        | 7 157                               | 7 317  | 7 340  | 7 393  | 7 419  | 7 446  | 7 473  | 7 500  | 7 527  | 7 554  | 7 581  | 7 609  | 7 636  | 7 664  | 7 692  | 7 719  | 7 748  | 7 776  |
| 8 000        | 8 180                               | 8 362  | 8 389  | 8 449  | 8 479  | 8 510  | 8 540  | 8 572  | 8 602  | 8 633  | 8 664  | 8 696  | 8 727  | 8 759  | 8 791  | 8 822  | 8 855  | 8 886  |
| 9 000        | 9 202                               | 9 408  | 9 437  | 9 505  | 9 539  | 9 574  | 9 608  | 9 643  | 9 678  | 9 712  | 9 747  | 9 783  | 9 818  | 9 854  | 9 890  | 9 925  | 9 962  | 9 997  |
| 10 000       | 10 225                              | 10 453 | 10 486 | 10 561 | 10 599 | 10 638 | 10 675 | 10 715 | 10 753 | 10 792 | 10 830 | 10 870 | 10 909 | 10 949 | 10 989 | 11 028 | 11 068 | 11 108 |
| 11 000       | 11 247                              | 11 498 | 11 535 | 11 617 | 11 659 | 11 701 | 11 743 | 11 786 | 11 828 | 11 871 | 11 913 | 11 956 | 12 000 | 12 044 | 12 088 | 12 131 | 12 175 | 12 219 |
| 12 000       | 12 270                              | 12 543 | 12 583 | 12 673 | 12 719 | 12 765 | 12 811 | 12 858 | 12 904 | 12 950 | 12 996 | 13 043 | 13 091 | 13 138 | 13 186 | 13 233 | 13 282 | 13 330 |
| 13 000       | 13 292                              | 13 589 | 13 632 | 13 729 | 13 779 | 13 829 | 13 878 | 13 929 | 13 979 | 14 029 | 14 079 | 14 130 | 14 182 | 14 233 | 14 285 | 14 336 | 14 389 | 14 440 |
| 14 000       | 14 315                              | 14 634 | 14 680 | 14 785 | 14 839 | 14 893 | 14 946 | 15 000 | 15 054 | 15 108 | 15 163 | 15 217 | 15 273 | 15 328 | 15 384 | 15 439 | 15 496 | 15 551 |
| 15 000       | 15 337                              | 15 679 | 15 729 | 15 841 | 15 899 | 15 957 | 16 013 | 16 072 | 16 129 | 16 187 | 16 246 | 16 304 | 16 363 | 16 423 | 16 483 | 16 542 | 16 603 | 16 662 |
| 16 000       | 16 360                              | 16 725 | 16 778 | 16 897 | 16 959 | 17 020 | 17 081 | 17 143 | 17 205 | 17 266 | 17 329 | 17 391 | 17 454 | 17 518 | 17 582 | 17 644 | 17 709 | 17 773 |
| 17 000       | 17 382                              | 17 770 | 17 826 | 17 953 | 18 018 | 18 084 | 18 148 | 18 215 | 18 280 | 18 346 | 18 412 | 18 478 | 18 545 | 18 613 | 18 681 | 18 747 | 18 816 | 18 884 |
| 18 000       | 18 405                              | 18 815 | 18 875 | 19 009 | 19 078 | 19 148 | 19 216 | 19 286 | 19 355 | 19 425 | 19 495 | 19 565 | 19 636 | 19 708 | 19 780 | 19 850 | 19 923 | 19 994 |
| 19 000       | 19 427                              | 19 860 | 19 923 | 20 065 | 20 138 | 20 212 | 20 283 | 20 358 | 20 431 | 20 504 | 20 578 | 20 652 | 20 727 | 20 802 | 20 878 | 20 953 | 21 030 | 21 105 |
| 20 000       | 20 450                              | 20 906 | 20 972 | 21 122 | 21 198 | 21 275 | 21 351 | 21 429 | 21 506 | 21 583 | 21 661 | 21 739 | 21 818 | 21 897 | 21 977 | 22 056 | 22 137 | 22 216 |
| 21 000       | 21 472                              | 21 951 | 22 021 | 22 178 | 22 258 | 22 339 | 22 418 | 22 501 | 22 581 | 22 662 | 22 744 | 22 826 | 22 909 | 22 992 | 23 076 | 23 158 | 23 244 | 23 327 |
| 22 000       | 22 495                              | 22 996 | 23 069 | 23 234 | 23 318 | 23 403 | 23 486 | 23 572 | 23 656 | 23 741 | 23 827 | 23 913 | 24 000 | 24 087 | 24 175 | 24 261 | 24 350 | 24 438 |
| 23 000       | 23 517                              | 24 041 | 24 118 | 24 290 | 24 378 | 24 467 | 24 554 | 24 644 | 24 732 | 24 820 | 24 910 | 25 000 | 25 091 | 25 182 | 25 274 | 25 364 | 25 457 | 25 548 |
| 24 000       | 24 540                              | 25 087 | 25 167 | 25 346 | 25 438 | 25 530 | 25 621 | 25 715 | 25 807 | 25 900 | 25 993 | 26 087 | 26 181 | 26 277 | 26 373 | 26 467 | 26 564 | 26 659 |
| 25 000       | 25 562                              | 26 132 | 26 215 | 26 402 | 26 498 | 26 594 | 26 689 | 26 787 | 26 882 | 26 979 | 27 076 | 27 174 | 27 272 | 27 372 | 27 472 | 27 569 | 27 671 | 27 770 |

## SHELMAC MC-3000

| MASS<br>(kg) | VOLUME (litres) at TEMPERATURE (°C) |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|--------------|-------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|              | 20                                  | 65   | 70   | 75   | 80   | 85   | 90   | 95   | 100  | 105  | 110  | 115  | 120  | 125  | 130  | 135  | 140  | 145  | 150  | 155  | 160  | 165  | 170  | 175  |
| 10           | 10                                  | 10   | 10   | 10   | 10   | 10   | 10   | 10   | 11   | 11   | 11   | 11   | 11   | 11   | 11   | 11   | 11   | 11   | 11   | 11   | 11   | 11   | 11   | 11   |
| 20           | 20                                  | 21   | 21   | 21   | 21   | 21   | 21   | 21   | 21   | 21   | 21   | 21   | 21   | 21   | 21   | 22   | 22   | 22   | 22   | 22   | 22   | 22   | 22   | 22   |
| 30           | 30                                  | 31   | 31   | 31   | 31   | 31   | 31   | 31   | 32   | 32   | 32   | 32   | 32   | 32   | 32   | 32   | 32   | 33   | 33   | 33   | 33   | 33   | 33   | 33   |
| 40           | 40                                  | 41   | 41   | 41   | 42   | 42   | 42   | 42   | 42   | 42   | 42   | 43   | 43   | 43   | 43   | 43   | 43   | 43   | 43   | 44   | 44   | 44   | 44   | 44   |
| 50           | 50                                  | 51   | 52   | 52   | 52   | 52   | 52   | 52   | 53   | 53   | 53   | 53   | 53   | 53   | 54   | 54   | 54   | 54   | 54   | 55   | 55   | 55   | 55   | 55   |
| 60           | 60                                  | 62   | 62   | 62   | 62   | 63   | 63   | 63   | 63   | 63   | 64   | 64   | 64   | 64   | 64   | 65   | 65   | 65   | 65   | 65   | 66   | 66   | 66   | 66   |
| 70           | 70                                  | 72   | 72   | 73   | 73   | 73   | 73   | 73   | 74   | 74   | 74   | 74   | 75   | 75   | 75   | 75   | 76   | 76   | 76   | 76   | 77   | 77   | 77   | 77   |
| 80           | 80                                  | 82   | 83   | 83   | 83   | 83   | 84   | 84   | 84   | 84   | 85   | 85   | 85   | 86   | 86   | 86   | 86   | 87   | 87   | 87   | 88   | 88   | 88   | 88   |
| 90           | 90                                  | 93   | 93   | 93   | 94   | 94   | 94   | 94   | 95   | 95   | 95   | 96   | 96   | 96   | 97   | 97   | 97   | 98   | 98   | 98   | 98   | 99   | 99   | 99   |
| 100          | 100                                 | 103  | 103  | 104  | 104  | 104  | 105  | 105  | 105  | 106  | 106  | 106  | 107  | 107  | 107  | 108  | 108  | 108  | 109  | 109  | 109  | 110  | 110  | 110  |
| 200          | 200                                 | 206  | 207  | 207  | 208  | 209  | 209  | 210  | 211  | 211  | 212  | 213  | 213  | 214  | 215  | 215  | 216  | 217  | 217  | 218  | 219  | 220  | 220  | 221  |
| 300          | 300                                 | 309  | 310  | 311  | 312  | 313  | 314  | 315  | 316  | 317  | 318  | 319  | 320  | 321  | 322  | 323  | 324  | 325  | 326  | 327  | 328  | 329  | 330  | 331  |
| 400          | 400                                 | 412  | 413  | 415  | 416  | 417  | 419  | 420  | 421  | 423  | 424  | 425  | 427  | 428  | 429  | 431  | 432  | 434  | 435  | 436  | 438  | 439  | 441  | 442  |
| 500          | 501                                 | 515  | 517  | 518  | 520  | 522  | 523  | 525  | 527  | 528  | 530  | 532  | 533  | 535  | 537  | 538  | 540  | 542  | 544  | 545  | 547  | 549  | 551  | 552  |
| 600          | 601                                 | 618  | 620  | 622  | 624  | 626  | 628  | 630  | 632  | 634  | 636  | 638  | 640  | 642  | 644  | 646  | 648  | 650  | 652  | 654  | 657  | 659  | 661  | 663  |
| 700          | 701                                 | 721  | 723  | 726  | 728  | 730  | 732  | 735  | 737  | 739  | 742  | 744  | 747  | 749  | 751  | 754  | 756  | 759  | 761  | 764  | 766  | 768  | 771  | 773  |
| 800          | 801                                 | 824  | 827  | 829  | 832  | 834  | 837  | 840  | 842  | 845  | 848  | 850  | 853  | 856  | 859  | 861  | 864  | 867  | 870  | 873  | 875  | 878  | 881  | 884  |
| 900          | 901                                 | 927  | 930  | 933  | 936  | 939  | 942  | 945  | 948  | 951  | 954  | 957  | 960  | 963  | 966  | 969  | 972  | 975  | 978  | 982  | 985  | 988  | 991  | 994  |
| 1000         | 1001                                | 1030 | 1033 | 1036 | 1040 | 1043 | 1046 | 1050 | 1053 | 1056 | 1060 | 1063 | 1067 | 1070 | 1073 | 1077 | 1080 | 1084 | 1087 | 1091 | 1094 | 1098 | 1101 | 1105 |
| 2000         | 2002                                | 2060 | 2066 | 2073 | 2079 | 2086 | 2093 | 2099 | 2106 | 2113 | 2119 | 2126 | 2133 | 2140 | 2147 | 2154 | 2161 | 2168 | 2174 | 2182 | 2188 | 2196 | 2203 | 2210 |
| 3000         | 3003                                | 3090 | 3099 | 3109 | 3119 | 3129 | 3139 | 3149 | 3159 | 3169 | 3179 | 3189 | 3200 | 3210 | 3220 | 3230 | 3241 | 3251 | 3262 | 3272 | 3283 | 3293 | 3304 | 3315 |
| 4000         | 4004                                | 4119 | 4133 | 4146 | 4159 | 4172 | 4185 | 4199 | 4212 | 4225 | 4239 | 4252 | 4266 | 4280 | 4293 | 4307 | 4321 | 4335 | 4349 | 4363 | 4377 | 4391 | 4405 | 4419 |
| 5000         | 5005                                | 5149 | 5166 | 5182 | 5198 | 5215 | 5232 | 5249 | 5265 | 5282 | 5299 | 5315 | 5333 | 5350 | 5367 | 5384 | 5401 | 5419 | 5436 | 5454 | 5471 | 5489 | 5507 | 5524 |

## SHELMAC MC-3000

| MASS<br>(kg) | VOLUME (litres) at TEMPERATURE (°C) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
|--------------|-------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|              | 20                                  | 65     | 70     | 75     | 80     | 85     | 90     | 95     | 100    | 105    | 110    | 115    | 120    | 125    | 130    | 135    | 140    | 145    | 150    | 155    | 160    | 165    | 170    | 175    |
| 6 000        | 6 006                               | 6 179  | 6 199  | 6 219  | 6 238  | 6 258  | 6 278  | 6 298  | 6 318  | 6 338  | 6 358  | 6 379  | 6 400  | 6 419  | 6 440  | 6 461  | 6 482  | 6 503  | 6 523  | 6 545  | 6 565  | 6 587  | 6 608  | 6 629  |
| 7 000        | 7 007                               | 7 209  | 7 232  | 7 255  | 7 278  | 7 301  | 7 324  | 7 348  | 7 371  | 7 394  | 7 418  | 7 442  | 7 466  | 7 489  | 7 513  | 7 538  | 7 562  | 7 587  | 7 611  | 7 635  | 7 660  | 7 685  | 7 709  | 7 734  |
| 8 000        | 8 008                               | 8 239  | 8 265  | 8 292  | 8 317  | 8 344  | 8 370  | 8 398  | 8 424  | 8 451  | 8 478  | 8 505  | 8 533  | 8 559  | 8 587  | 8 614  | 8 642  | 8 670  | 8 698  | 8 726  | 8 754  | 8 783  | 8 811  | 8 839  |
| 9 000        | 9 009                               | 9 269  | 9 298  | 9 328  | 9 357  | 9 387  | 9 417  | 9 447  | 9 477  | 9 507  | 9 537  | 9 568  | 9 599  | 9 629  | 9 660  | 9 691  | 9 723  | 9 754  | 9 785  | 9 817  | 9 848  | 9 880  | 9 912  | 9 944  |
| 10 000       | 10 010                              | 10 298 | 10 331 | 10 364 | 10 397 | 10 430 | 10 463 | 10 497 | 10 530 | 10 564 | 10 597 | 10 631 | 10 666 | 10 699 | 10 733 | 10 768 | 10 803 | 10 838 | 10 872 | 10 908 | 10 942 | 10 978 | 11 013 | 11 049 |
| 11 000       | 11 011                              | 11 328 | 11 364 | 11 401 | 11 436 | 11 473 | 11 509 | 11 547 | 11 583 | 11 620 | 11 657 | 11 694 | 11 733 | 11 769 | 11 807 | 11 845 | 11 883 | 11 922 | 11 959 | 11 998 | 12 037 | 12 076 | 12 115 | 12 153 |
| 12 000       | 12 012                              | 12 358 | 12 398 | 12 437 | 12 476 | 12 516 | 12 556 | 12 596 | 12 636 | 12 676 | 12 717 | 12 757 | 12 799 | 12 839 | 12 880 | 12 922 | 12 964 | 13 006 | 13 047 | 13 089 | 13 131 | 13 174 | 13 216 | 13 258 |
| 13 000       | 13 013                              | 13 388 | 13 431 | 13 474 | 13 516 | 13 559 | 13 602 | 13 646 | 13 689 | 13 733 | 13 776 | 13 820 | 13 866 | 13 909 | 13 953 | 13 999 | 14 044 | 14 089 | 14 134 | 14 180 | 14 225 | 14 272 | 14 317 | 14 363 |
| 14 000       | 14 014                              | 14 418 | 14 464 | 14 510 | 14 555 | 14 602 | 14 648 | 14 696 | 14 742 | 14 789 | 14 836 | 14 883 | 14 932 | 14 979 | 15 027 | 15 075 | 15 124 | 15 173 | 15 221 | 15 271 | 15 319 | 15 370 | 15 419 | 15 468 |
| 15 000       | 15 015                              | 15 448 | 15 497 | 15 547 | 15 595 | 15 646 | 15 695 | 15 746 | 15 795 | 15 845 | 15 896 | 15 946 | 15 999 | 16 049 | 16 100 | 16 152 | 16 204 | 16 257 | 16 308 | 16 362 | 16 413 | 16 467 | 16 520 | 16 573 |
| 16 000       | 16 016                              | 16 477 | 16 530 | 16 583 | 16 635 | 16 689 | 16 741 | 16 795 | 16 848 | 16 902 | 16 955 | 17 009 | 17 066 | 17 118 | 17 174 | 17 229 | 17 285 | 17 341 | 17 395 | 17 452 | 17 508 | 17 565 | 17 621 | 17 678 |
| 17 000       | 17 017                              | 17 507 | 17 563 | 17 620 | 17 675 | 17 732 | 17 787 | 17 845 | 17 901 | 17 958 | 18 015 | 18 072 | 18 132 | 18 188 | 18 247 | 18 306 | 18 365 | 18 425 | 18 483 | 18 543 | 18 602 | 18 663 | 18 723 | 18 783 |
| 18 000       | 18 018                              | 18 537 | 18 596 | 18 656 | 18 714 | 18 775 | 18 834 | 18 895 | 18 954 | 19 014 | 19 075 | 19 136 | 19 199 | 19 258 | 19 320 | 19 383 | 19 445 | 19 508 | 19 570 | 19 634 | 19 696 | 19 761 | 19 824 | 19 887 |
| 19 000       | 19 019                              | 19 567 | 19 629 | 19 693 | 19 754 | 19 818 | 19 880 | 19 944 | 20 007 | 20 071 | 20 134 | 20 199 | 20 265 | 20 328 | 20 394 | 20 459 | 20 526 | 20 592 | 20 657 | 20 725 | 20 790 | 20 859 | 20 925 | 20 992 |
| 20 000       | 20 020                              | 20 597 | 20 663 | 20 729 | 20 794 | 20 861 | 20 926 | 20 994 | 21 060 | 21 127 | 21 194 | 21 262 | 21 332 | 21 398 | 21 467 | 21 536 | 21 606 | 21 676 | 21 744 | 21 815 | 21 885 | 21 957 | 22 027 | 22 097 |
| 21 000       | 21 021                              | 21 627 | 21 696 | 21 765 | 21 833 | 21 904 | 21 972 | 22 044 | 22 113 | 22 183 | 22 254 | 22 325 | 22 399 | 22 468 | 22 540 | 22 613 | 22 686 | 22 760 | 22 832 | 22 906 | 22 979 | 23 054 | 23 128 | 23 202 |
| 22 000       | 22 022                              | 22 656 | 22 729 | 22 802 | 22 873 | 22 947 | 23 019 | 23 094 | 23 166 | 23 240 | 23 314 | 23 388 | 23 465 | 23 538 | 23 614 | 23 690 | 23 766 | 23 844 | 23 919 | 23 997 | 24 073 | 24 152 | 24 229 | 24 307 |
| 23 000       | 23 023                              | 23 686 | 23 762 | 23 838 | 23 913 | 23 990 | 24 065 | 24 143 | 24 219 | 24 296 | 24 373 | 24 451 | 24 532 | 24 608 | 24 687 | 24 767 | 24 847 | 24 927 | 25 006 | 25 088 | 25 167 | 25 250 | 25 331 | 25 412 |
| 24 000       | 24 024                              | 24 716 | 24 795 | 24 875 | 24 952 | 25 033 | 25 111 | 25 193 | 25 272 | 25 352 | 25 433 | 25 514 | 25 598 | 25 678 | 25 760 | 25 843 | 25 927 | 26 011 | 26 093 | 26 179 | 26 262 | 26 348 | 26 432 | 26 517 |
| 25 000       | 25 025                              | 25 746 | 25 828 | 25 911 | 25 992 | 26 076 | 26 158 | 26 243 | 26 326 | 26 409 | 26 493 | 26 577 | 26 665 | 26 748 | 26 834 | 26 920 | 27 007 | 27 095 | 27 180 | 27 269 | 27 356 | 27 446 | 27 533 | 27 621 |

# APPENDIX B

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## ABBREVIATIONS

|          |                                                          |
|----------|----------------------------------------------------------|
| ISBN     | International Standard Book Number                       |
| ISSN     | International Standard Serie Number                      |
| MC       | Medium curing                                            |
| NORAD    | Norwegian Agency for Development Cooperation             |
| NPRA     | Norwegian Public Roads Administration                    |
| NRRL     | Norwegian Road Research Laboratory                       |
| PHN      | Public Highway Network                                   |
| PVA      | Polyvinyleacelate                                        |
| RC       | Rapid Curing                                             |
| SBR      | Styrenebutadinerubber                                    |
| SBS      | Styrenebutadinstyrene                                    |
| SC       | Slow Curing                                              |
| SFRDP    | Feeder Road Development Programme                        |
| Sida     | Swedish International Development Authority              |
| SPMB     | Semi-Priming Modified Binder                             |
| TMH      | Technical Methods for Highways (South African Standards) |
| 10% FACT | Ten percent Fines Value                                  |
| AADT     | Average Annual Daily Traffic                             |

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