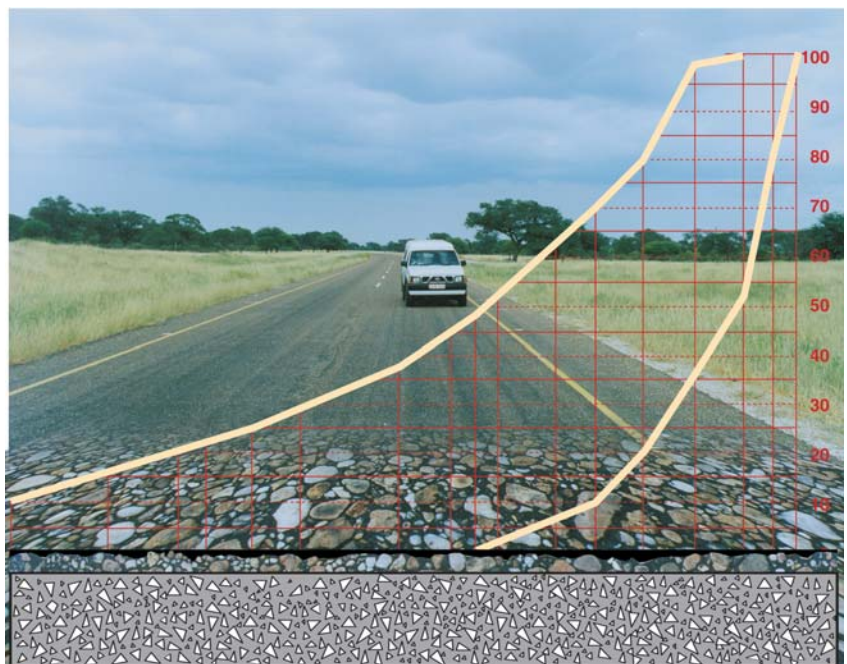


A Guide to the Use of Otta Seals



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By Charles Øverby

A Guide to the Use of Otta Seals

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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, 10th 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

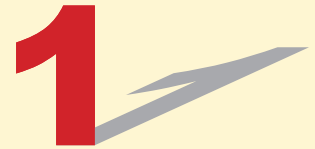
The main purpose of this Guideline is to provide practical guidance on the design, construction and maintenance of Otta Seals. The Guideline also summarises the experience that has been gained in the use of the Otta Seal for the last three decades in a global perspective. In so doing, the intention is 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.

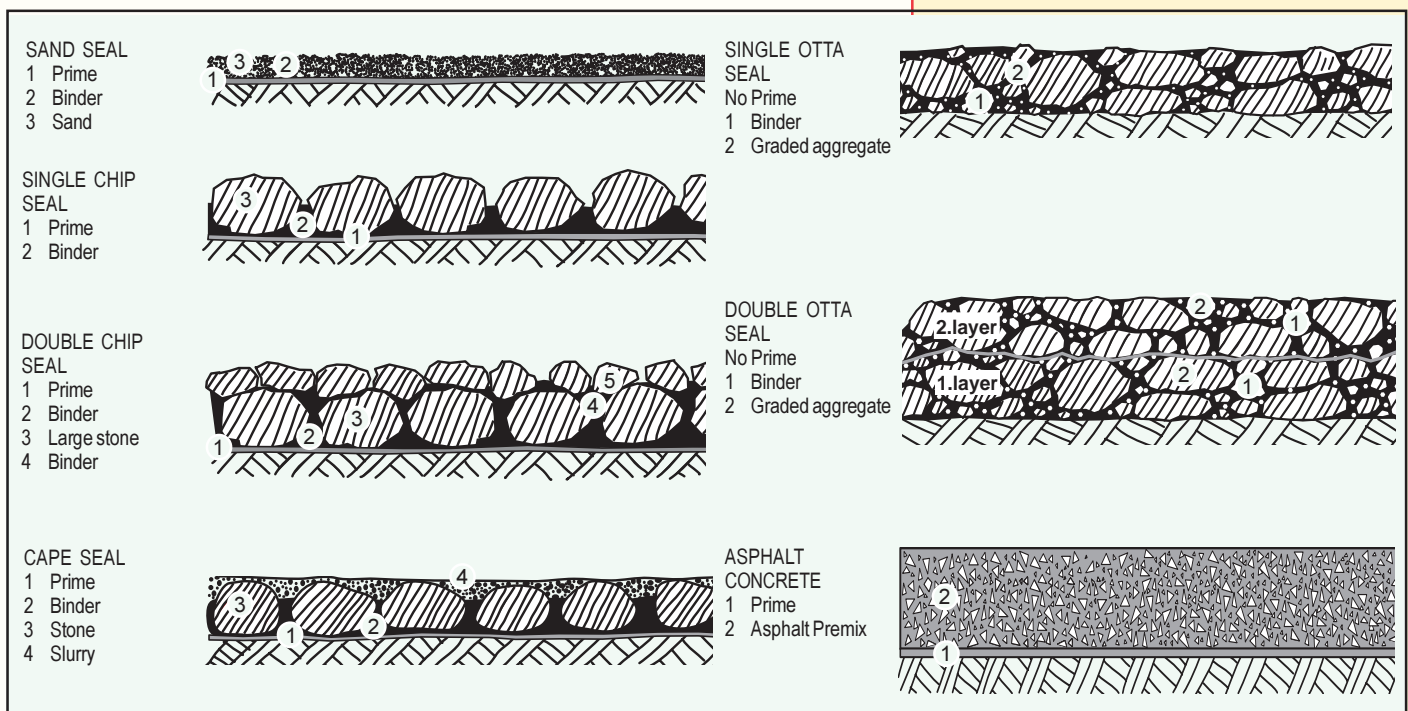


Figure 2.1 Schematic illustration of various types of bituminous surfacings.

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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.

4

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

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.

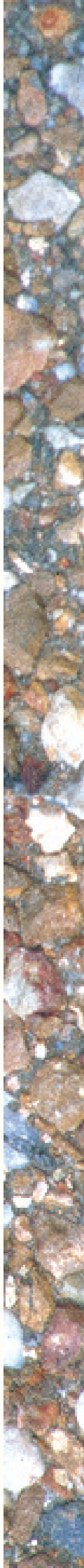
Trafficking of the seal immediately after rolling is desirable and its final appearance is formed after 4 - 8 weeks giving a “premix” like appearance in the wheel paths. Priming of the base is normally not required.

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.

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



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 blined 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.

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.

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!



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
Aggregate quality	Relaxed requirements for: <ul style="list-style-type: none"> - strength - grading - particle shape - binder adhesion - dust content Maximises use of locally available natural gravel or of the crushed product.	Stringent requirements for: <ul style="list-style-type: none"> - strength - grading - particle shape - binder adhesion - dust content Maximised use of the crushed product is difficult, use of natural gravel is in practice inappropriate
Binder	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).
Design	Empirical approach to design. Relied earlier to a large extent on experience and site trials.	Empirically based rational design methods.
Construction technique	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.
Construction costs	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).
Contractual matters	Additional contractual issues need to be resolved.	Contractual issues well-known
Aesthetics	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.
Skid resistance in wet weather	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.
Use on fresh bituminous base layers	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.
Periodic maintenance between reseals	Generally little need for periodic maintenance between reseals.	Rejuvenation with emulsion fog spray between reseals is normally required for maintaining stone retention.
Durability of the seal	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.
Typical service life	Typical service life: <ul style="list-style-type: none"> - Double Otta Seal: 12 - 15 years - Single Otta Seal with a sand cover seal: 9 - 11 years 	Typical service life : <ul style="list-style-type: none"> - Double Chip Seal: 8 - 10 years - Single Chip Seal: 5 - 6 years Adequately workmanship is essential

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

5

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”.



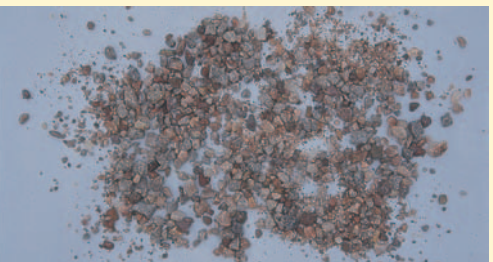
“As dug material” which in many cases only requires screening of oversize materials, can successfully be used in Otta Seals. (Kenya).



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.

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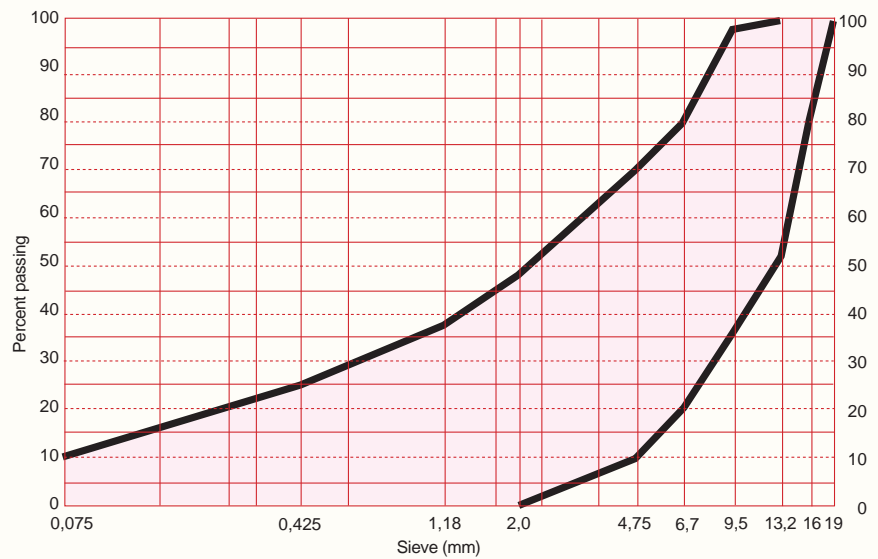


Figure 5.1 General grading envelope for Otta Seal aggregates

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.

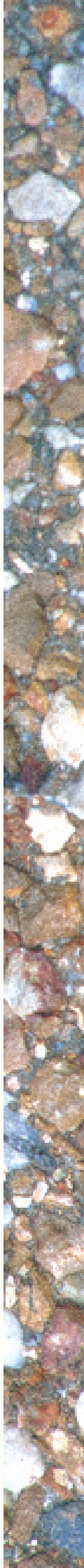
Flakiness

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

6.1 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.

6

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.

6

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 (Rapid Curing)	Petrol	Hazardous, should not be used
MC (Medium Curing)	Kerosene (Power paraffin Illuminating paraffin, JetA1 aviation turbine fuel)	Suitable for Otta Seals
SC (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.

6

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.



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

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.

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.



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/m². 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.

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 AADT > 500	Low traffic 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.



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.

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

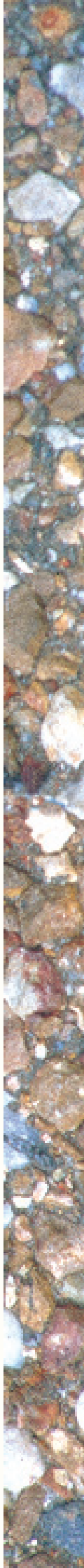
The Double Otta Seal is the most durable, but also the most expensive and is recommended for main roads carrying high volumes of traffic. Double Otta Seals with a cover sand seal are seldom specified due to their high costs and marginal benefits.

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.



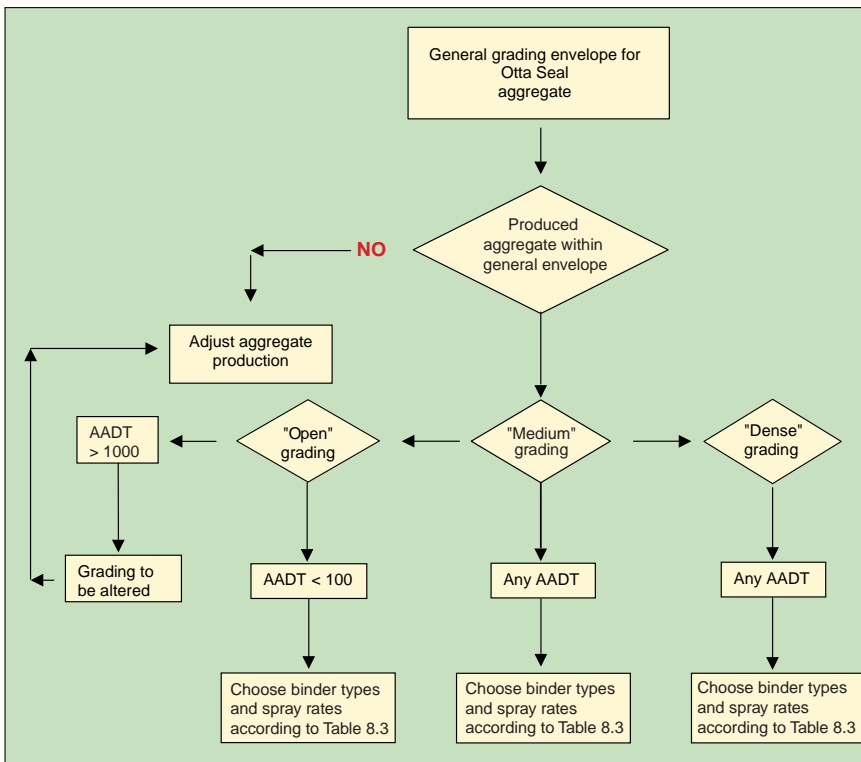


Figure 8.1 Flow chart for the design procedures of Otta Seals.

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.

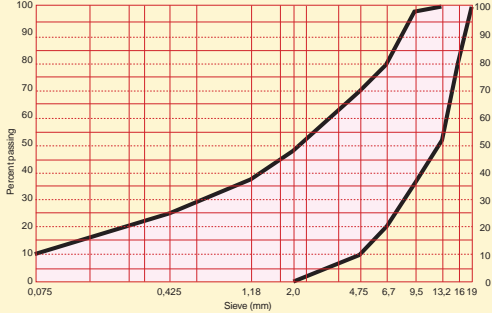
As guidance for the designer of Otta Seals, three grading envelopes, depending on traffic, have been produced to allow for a more rational design. However,

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

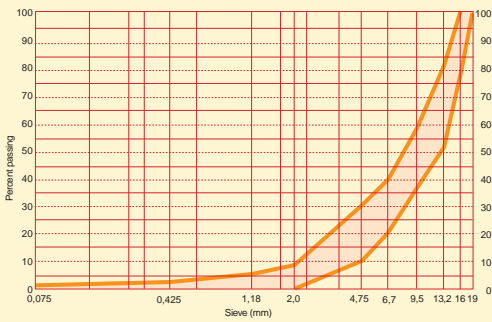
The aggregate application rates for an Otta Seal will appear excessive in comparison with that for a conventional Chip Seal

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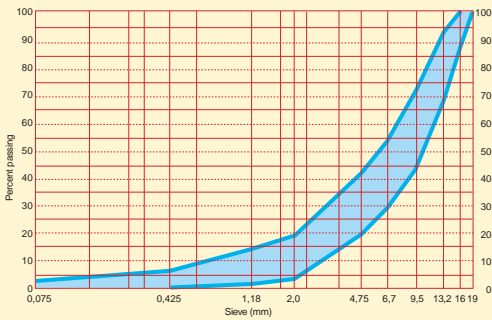
General aggregate grading requirements



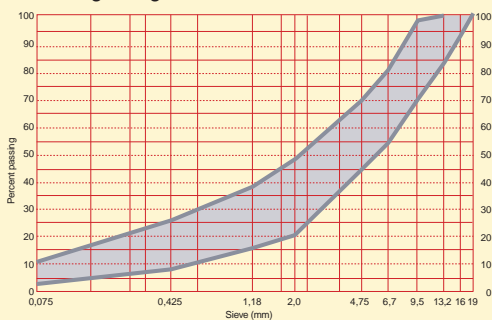
Open grading



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/m². (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/m² 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/m².

In the case where the base has been primed the hot spray rate should be decreased by 0,2 l/m² for the first layer.

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

1. ALTERNATIVE GRADING ENVELOPES

Sieve sizes (mm)	Open grading	Medium grading	Dense grading	AASHTO or BS Test designation
	(% passing)	(% passing)	(% passing)	
19	100	100	100	T 146-49 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 time of construction	Type of bitumen		
	Open grading	Medium grading	Dense grading
More than 1000	Not applicable	150/200 pen. grade	MC 3000 MC 800 in cold weather
100 - 1000	150/200 pen. grade	150/200 pen. grade in cold weather	MC 3000 MC 800 in cold 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/m²)

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/m² 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/m².
 - 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 ³ /m ²)		
	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.



A too excessive aggregate application. (Botswana).



Correct aggregate application rate. (Botswana).

Table 8.3 b Design procedures for Otta Seals.

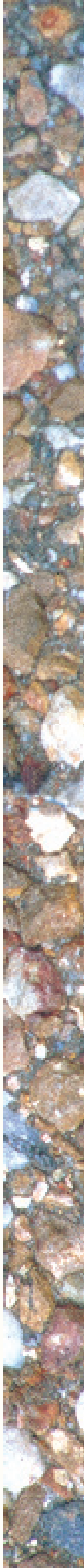
8.6 Aggregate application rates

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.



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.

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.

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.

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.

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.



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

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:



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

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.

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).

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.



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

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.

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) + 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 1st 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/m² 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.

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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

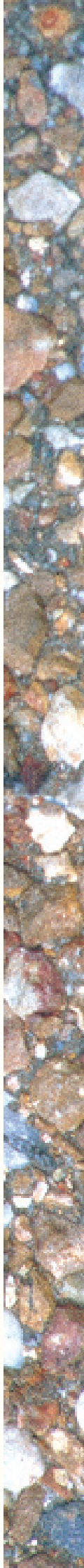
Rolling using pneumatic equipment

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.

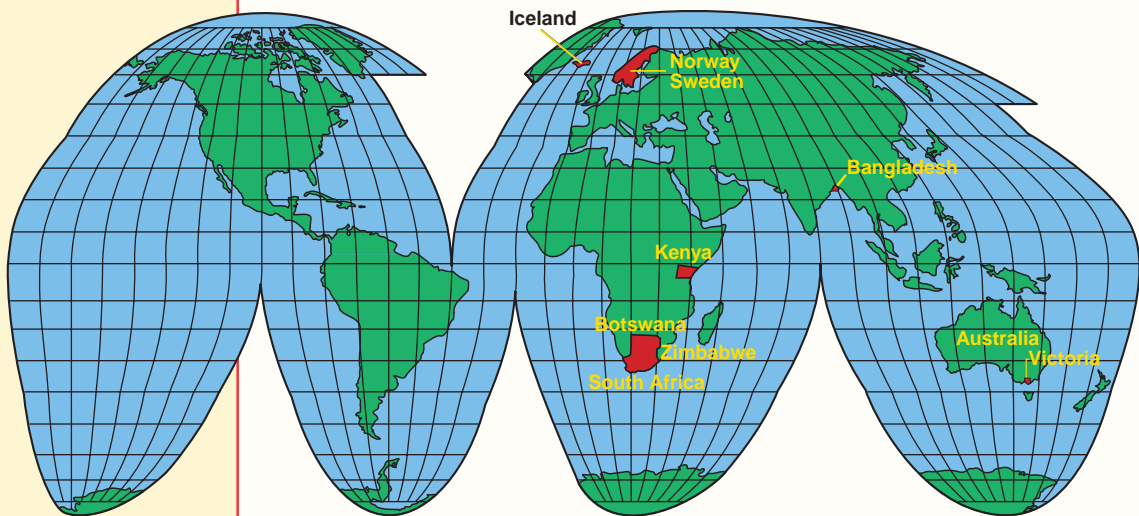


Figure 12.1 The global use of Otta Seals

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/m².
- 2nd. seal 0-11 mm 18-20 kg/m² (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/m². BE between 1,9 - 2,1 l/m²

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/m².



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_{soaked} 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/m² 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/m², 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.

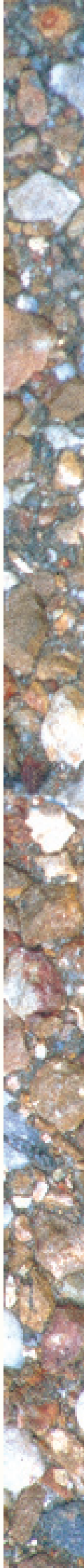
The use of Otta Seals is included in the Kenyan Road Design Manual of 1987.

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/m².



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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/m², 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).

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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/m². 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/m² 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 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 Seala 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 show 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 (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
1000	978	1029	1033	1036	1039	1043	1046	1049	1053	1056	1059	1063	1066	1070	1073	1077	1080	1083	1087	1095
2000	1957	2059	2065	2072	2078	2085	2092	2098	2105	2112	2119	2125	2132	2139	2146	2153	2160	2167	2174	2190
3000	2935	3088	3098	3108	3117	3128	3137	3148	3158	3168	3178	3188	3199	3209	3219	3230	3240	3250	3261	3285
4000	3914	4117	4130	4143	4157	4170	4183	4197	4210	4224	4238	4251	4265	4278	4292	4306	4320	4334	4348	4379
5000	4892	5147	5163	5179	5196	5213	5229	5246	5263	5280	5297	5314	5331	5348	5366	5383	5400	5417	5435	5474

MEXPHALTE 80/100

MASS (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
6000	5871	6176	6195	6215	6235	6256	6275	6295	6315	6336	6356	6376	6397	6418	6439	6459	6480	6501	6522	6569
7000	6849	7205	7228	7251	7274	7298	7321	7344	7368	7392	7416	7439	7464	7487	7512	7536	7560	7584	7609	7664
8000	7828	8235	8261	8287	8313	8341	8367	8394	8421	8448	8475	8502	8530	8557	8585	8612	8640	8668	8696	8759
9000	8806	9264	9293	9323	9352	9383	9412	9443	9473	9504	9535	9566	9596	9626	9658	9689	9720	9751	9783	9854
10000	9785	10293	10326	10359	10392	10426	10458	10492	10526	10560	10594	10627	10662	10696	10731	10765	10800	10835	10870	10949
11000	10763	11323	11358	11394	11431	11469	11504	11541	11578	11616	11654	11690	11728	11766	11804	11842	11880	11918	11956	12043
12000	11742	12352	12391	12430	12470	12511	12550	12590	12631	12672	12713	12753	12795	12835	12877	12919	12960	13002	13043	13138
13000	12720	13381	13424	13466	13509	13554	13596	13639	13683	13728	13772	13816	13861	13905	13951	13995	14040	14085	14130	14233
14000	13699	14411	14456	14502	14548	14596	14642	14689	14736	14784	14832	14878	14927	14974	15024	15072	15120	15168	15217	15328
15000	14677	15440	15489	15538	15587	15639	15687	15738	15789	15840	15891	15941	15993	16044	16097	16148	16200	16252	16304	16423
16000	15656	16469	16521	16574	16627	16681	16733	16787	16841	16896	16951	17004	17060	17114	17170	17225	17280	17335	17391	17518
17000	16634	17498	17554	17610	17666	17724	17779	17836	17894	17952	18010	18067	18126	18183	18243	18301	18360	18419	18478	18613
18000	17613	18528	18586	18645	18705	18767	18825	18885	18946	19008	19069	19129	19192	19253	19316	19378	19440	19502	19565	19707
19000	18591	19557	19619	19681	19744	19809	19871	19935	19999	20064	20129	20192	20258	20322	20389	20454	20520	20586	20652	20802
20000	19569	20586	20652	20717	20783	20852	20916	20984	21051	21120	21188	21255	21324	21392	21462	21531	21600	21669	21739	21897
21000	20548	21616	21684	21753	21822	21894	21962	22033	22104	22176	22248	22318	22391	22462	22536	22607	22680	22753	22826	22992
22000	21526	22645	22717	22789	22862	22937	23008	23082	23157	23232	23307	23380	23457	23531	23609	23684	23760	23836	23913	24087
23000	22505	23674	23749	23825	23901	23980	24054	24131	24209	24288	24366	24443	24523	24601	24682	24761	24840	24920	25000	25182
24000	23483	24704	24782	24861	24940	25022	25100	25181	25262	25344	25426	25506	25589	25670	25755	25837	25920	26003	26087	26277
25000	24462	25733	25815	25897	25979	26065	26146	26230	26314	26400	26485	26569	26656	26740	26828	26914	27000	27087	27174	27371

SPRAMEX 150/200

MASS (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
1000	987	1032	1035	1038	1042	1045	1048	1052	1055	1059	1062	1065	1069	1072	1076	1079	1083	1086	1090	1093
2000	1974	2064	2070	2077	2084	2090	2097	2104	2110	2117	2124	2131	2138	2144	2151	2158	2165	2172	2179	2186
3000	2962	3096	3106	3115	3125	3135	3145	3156	3165	3176	3186	3196	3206	3217	3227	3237	3248	3258	3269	3279
4000	3949	4127	4141	4154	4167	4180	4194	4207	4220	4234	4248	4261	4275	4289	4303	4316	4331	4344	4358	4372
5000	4936	5159	5176	5192	5209	5225	5242	5259	5276	5293	5310	5327	5344	5361	5378	5396	5413	5431	5448	5465

SPRAMEX 150/200

MASS (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
6000	5923	6191	6211	6231	6251	6270	6290	6311	6331	6351	6372	6392	6413	6433	6454	6475	6496	6517	6538	6559
7000	6910	7223	7246	7269	7292	7315	7339	7363	7386	7410	7433	7458	7482	7505	7530	7554	7579	7603	7627	7652
8000	7897	8255	8282	8308	8334	8361	8387	8415	8441	8468	8495	8523	8551	8578	8606	8633	8661	8689	8717	8745
9000	8885	9287	9317	9346	9376	9406	9436	9467	9496	9527	9557	9588	9619	9650	9681	9712	9744	9775	9806	9838
10000	9872	10318	10352	10385	10418	10451	10484	10519	10551	10585	10619	10654	10688	10722	10757	10791	10827	10861	10896	10931
11000	10859	11350	11387	11423	11459	11496	11532	11570	11606	11644	11681	11719	11757	11794	11833	11870	11909	11947	11985	12024
12000	11846	12382	12422	12462	12501	12541	12581	12622	12661	12702	12743	12784	12826	12866	12908	12949	12992	13033	13075	13117
13000	12833	13414	13458	13500	13543	13586	13629	13674	13717	13761	13805	13850	13895	13938	13984	14028	14075	14119	14165	14210
14000	13820	14446	14493	14539	14585	14631	14678	14726	14772	14819	14867	14915	14964	15011	15060	15107	15157	15206	15254	15303
15000	14808	15478	15528	15577	15626	15676	15726	15778	15827	15878	15929	15980	16032	16083	16135	16187	16240	16292	16344	16396
16000	15795	16510	16563	16615	16668	16721	16774	16830	16882	16936	16991	17046	17101	17155	17211	17266	17323	17378	17433	17489
17000	16782	17541	17598	17654	17710	17766	17823	17882	17937	17995	18053	18111	18170	18227	18287	18345	18405	18464	18523	18582
18000	17769	18573	18634	18692	18752	18811	18871	18933	18992	19053	19115	19177	19239	19299	19363	19424	19488	19550	19613	19676
19000	18756	19605	19669	19731	19793	19856	19919	19985	20047	20112	20177	20242	20308	20372	20438	20503	20570	20636	20702	20769
20000	19743	20637	20704	20769	20835	20901	20968	21037	21102	21170	21239	21307	21377	21444	21514	21582	21653	21722	21792	21862
21000	20731	21669	21739	21808	21877	21946	22016	22089	22157	22229	22300	22373	22445	22516	22590	22661	22736	22808	22881	22955
22000	21718	22701	22774	22846	22919	22991	23065	23141	23213	23287	23362	23438	23514	23588	23665	23740	23818	23894	23971	24048
23000	22705	23732	23810	23885	23960	24036	24113	24193	24268	24346	24424	24503	24583	24660	24741	24819	24901	24981	25061	25141
24000	23692	24764	24845	24923	25002	25082	25161	25245	25323	25404	25486	25569	25652	25733	25817	25899	25984	26067	26150	26234
25000	24679	25796	25880	25962	26044	26127	26210	26296	26378	26463	26548	26634	26721	26805	26892	26978	27066	27153	27240	27327

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MASS (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	94	95	95	96	96	96	97	97	97	98	98	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	1000
1000	1022	1045	1049	1056	1060	1064	1068	1071	1075	1079	1083	1087	1091	1095	1099	1103	1107	1111
2000	2045	2091	2097	2112	2120	2128	2135	2143	2151	2158	2166	2174	2182	2190	2198	2206	2214	2222
3000	3067	3136	3146	3168	3180	3191	3203	3214	3226	3237	3249	3261	3273	3285	3297	3308	3321	3332
4000	4090	4181	4194	4224	4240	4255	4270	4286	4301	4317	4332	4348	4364	4379	4395	4411	4427	4443
5000	5112	5226	5243	5280	5300	5319	5338	5357	5376	5396	5415	5435	5454	5474	5494	5514	5534	5554

SHELMAC MC-800

MASS (kg)	VOLUME (litres) at TEMPERATURE (°C)																	
	20	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135
6000	6135	6272	6292	6336	6359	6383	6405	6429	6452	6475	6498	6522	6545	6569	6593	6617	6641	6665
7000	7157	7317	7340	7393	7419	7446	7473	7500	7527	7554	7581	7609	7636	7664	7692	7719	7748	7776
8000	8180	8362	8389	8449	8479	8510	8540	8572	8602	8633	8664	8696	8727	8759	8791	8822	8855	8886
9000	9202	9408	9437	9505	9539	9574	9608	9643	9678	9712	9747	9783	9818	9854	9890	9925	9962	9997
10000	10225	10453	10486	10561	10599	10638	10675	10715	10753	10792	10830	10870	10909	10949	10989	11028	11068	11108
11000	11247	11498	11535	11617	11659	11701	11743	11786	11828	11871	11913	11956	12000	12044	12088	12131	12175	12219
12000	12270	12543	12583	12673	12719	12765	12811	12858	12904	12950	12996	13043	13091	13138	13186	13233	13282	13330
13000	13292	13589	13632	13729	13779	13829	13878	13929	13979	14029	14079	14130	14182	14233	14285	14336	14389	14440
14000	14315	14634	14680	14785	14839	14893	14946	15000	15054	15108	15163	15217	15273	15328	15384	15439	15496	15551
15000	15337	15679	15729	15841	15899	15957	16013	16072	16129	16187	16246	16304	16363	16423	16483	16542	16603	16662
16000	16360	16725	16778	16897	16959	17020	17081	17143	17205	17266	17329	17391	17454	17518	17582	17644	17709	17773
17000	17382	17770	17826	17953	18018	18084	18148	18215	18280	18346	18412	18478	18545	18613	18681	18747	18816	18884
18000	18405	18815	18875	19009	19078	19148	19216	19286	19355	19425	19495	19565	19636	19708	19780	19850	19923	19994
19000	19427	19860	19923	20065	20138	20212	20283	20358	20431	20504	20578	20652	20727	20802	20878	20953	21030	21105
20000	20450	20906	20972	21122	21198	21275	21351	21429	21506	21583	21661	21739	21818	21897	21977	22056	22137	22216
21000	21472	21951	22021	22178	22258	22339	22418	22501	22581	22662	22744	22826	22909	22992	23076	23158	23244	23327
22000	22495	22996	23069	23234	23318	23403	23486	23572	23656	23741	23827	23913	24000	24087	24175	24261	24350	24438
23000	23517	24041	24118	24290	24378	24467	24554	24644	24732	24820	24910	25000	25091	25182	25274	25364	25457	25548
24000	24540	25087	25167	25346	25438	25530	25621	25715	25807	25900	25993	26087	26181	26277	26373	26467	26564	26659
25000	25562	26132	26215	26402	26498	26594	26689	26787	26882	26979	27076	27174	27272	27372	27472	27569	27671	27770

SHELMAC MC-3000

MASS (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	31	32	32	32	32	32	32	32	32	32	32	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	85	85	85	85	86	86	86	86	86	87	87	87	88	88	88
90	90	93	93	93	94	94	94	94	95	95	95	96	96	96	97	97	97	97	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 (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
6000	6006	6179	6199	6219	6238	6258	6278	6298	6318	6338	6358	6379	6400	6419	6440	6461	6482	6503	6523	6545	6565	6587	6608	6629
7000	7007	7209	7232	7255	7278	7301	7324	7348	7371	7394	7418	7442	7466	7489	7513	7538	7562	7587	7611	7635	7660	7685	7709	7734
8000	8008	8239	8265	8292	8317	8344	8370	8398	8424	8451	8478	8505	8533	8559	8587	8614	8642	8670	8698	8726	8754	8783	8811	8839
9000	9009	9269	9298	9328	9357	9387	9417	9447	9477	9507	9537	9568	9599	9629	9660	9691	9723	9754	9785	9817	9848	9880	9912	9944
10000	10010	10298	10331	10364	10397	10430	10463	10497	10530	10564	10597	10631	10666	10699	10733	10768	10803	10838	10872	10908	10942	10978	11013	11049
11000	11011	11328	11364	11401	11436	11473	11509	11547	11583	11620	11657	11694	11733	11769	11807	11845	11883	11922	11959	11998	12037	12076	12115	12153
12000	12012	12358	12398	12437	12476	12516	12556	12596	12636	12676	12717	12757	12799	12839	12880	12922	12964	13006	13047	13089	13131	13174	13216	13258
13000	13013	13388	13431	13474	13516	13559	13602	13646	13689	13733	13776	13820	13866	13909	13953	13999	14044	14089	14134	14180	14225	14272	14317	14363
14000	14014	14418	14464	14510	14555	14602	14648	14696	14742	14789	14836	14883	14932	14979	15027	15075	15124	15173	15221	15271	15319	15370	15419	15468
15000	15015	15448	15497	15547	15595	15646	15695	15746	15795	15845	15896	15946	15999	16049	16100	16152	16204	16257	16308	16362	16413	16467	16520	16573
16000	16016	16477	16530	16583	16635	16689	16741	16795	16848	16902	16955	17009	17066	17118	17174	17229	17285	17341	17395	17452	17508	17565	17621	17678
17000	17017	17507	17563	17620	17675	17732	17787	17845	17901	17958	18015	18072	18132	18188	18247	18306	18365	18425	18483	18543	18602	18663	18723	18783
18000	18018	18537	18596	18656	18714	18775	18834	18895	18954	19014	19075	19136	19199	19258	19320	19383	19445	19508	19570	19634	19696	19761	19824	19887
19000	19019	19567	19629	19693	19754	19818	19880	19944	20007	20071	20134	20199	20265	20328	20394	20459	20526	20592	20657	20725	20790	20859	20925	20992
20000	20020	20597	20663	20729	20794	20861	20926	20994	21060	21127	21194	21262	21332	21398	21467	21536	21606	21676	21744	21815	21885	21957	22027	22097
21000	21021	21627	21696	21765	21833	21904	21972	22044	22113	22183	22254	22325	22399	22468	22540	22613	22686	22760	22832	22906	22979	23054	23128	23202
22000	22022	22656	22729	22802	22873	22947	23019	23094	23166	23240	23314	23388	23465	23538	23614	23690	23766	23844	23919	23997	24073	24152	24229	24307
23000	23023	23686	23762	23838	23913	23990	24065	24143	24219	24296	24373	24451	24532	24608	24687	24767	24847	24927	25006	25088	25167	25250	25331	25412
24000	24024	24716	24795	24875	24952	25033	25111	25193	25272	25352	25433	25514	25598	25678	25760	25843	25927	26011	26093	26179	26262	26348	26432	26517
25000	25025	25746	25828	25911	25992	26076	26158	26243	26326	26409	26493	26577	26665	26748	26834	26920	27007	27095	27180	27269	27356	27446	27533	27621

APPENDIX B

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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