
The Otta Seal Surfacing

**An economic and practical alternative to
traditional bituminous surface treatments**



Charles Overby - Norwegian Public Roads Administration
Michael I. Pinard - InfraAfrica Consultants, Botswana

October 2007

The Otta seal Surfacing
**An economic and practical alternative to
traditional bituminous surface treatments**

Charles Overby - Norwegian Public Roads Administration
Michael I. Pinard - InfraAfrica Consultants, Botswana

October 2007

CONTENTS

Foreword	iii
Abstract	iv
Acknowledgements	v
List of Acronyms	vi
Overview and Conclusions	vii
1. Introduction	1
Background.....	1
Purpose and Scope.....	1
Structure and Content	2
2. Roads, Development and Poverty Reduction	3
Road Transport Infrastructure and Development	3
Rural Accessibility and Poverty Reduction.....	3
Sustainability of Gravel Roads	4
The Case for Low-Cost Sealed Roads	5
3. Bituminous Surfacing	7
Functions	7
Types	7
Mechanism of Performance Under Traffic.....	8
Service Life	9
Factors affecting choice of Surfacing.....	9
4. The Otta Seal Surfacing	11
Origin and Initial Use	11
Description and Types	11
Properties	12
Design.....	14
Construction	15
Maintenance and Reseals.....	16
5. Characteristics of the Otta Seal	17
Relative Differences between Otta seals and Traditional Seals	17
Performance Characteristics	17
Economic Characteristics	18
Relative Advantages and Disadvantages	19
6. Impacts and Sustainability of the Otta Seal	21
General	21
Political	21
Socio-Economic	21
Institutional.....	22
Technical	23
Economic and Financial	23
Environmental	24

7. Global Use of the Otta seal	25
Introduction of Innovative Technology	25
Meeting the Challenges	25
Use of the Otta seal	25
The Future of the Otta seal	26
Case Histories.....	26
8. Conclusions and Recommendations	28
Summary of Conclusions.....	28
Summary of Recommendations.....	28
9. Appendices	
Various photographs of Otta seal surfacing, incl. close-up photographs.....	29
10. Bibliography	35

List of Tables

Table 3.1 - Typical range of service lives of bituminous surface treatments.....	9
Table 4.1 - Recommended type of Otta seals in relation to traffic levels	12
Table 4.2 - General guide for Otta seal binder spray rates.....	14
Table 4.3 - Labour-friendliness of various surfacing types	16
Table 5.1 - Relative differences between Otta seals and traditional seals	17
Table 7.1 - Length of Otta seals constructed in various countries (as per 2004).....	26

List of Figures

Figure 3.1 - Schematic of common types of bituminous surfacings.....	7
Figure 3.2 - Mechanism of performance of surfacing types	8
Figure 4.1 - Difference in make-up of single Chip seal and single Otta seal.....	12
Figure 4.2 - Grading and aggregate strength for an Otta seal	13
Figure 5.1 - Life-cycle cost comparison between an Otta seal and a Chip seal.....	19
Figure 6.1 - Elements of sustainability of the Otta seal	21
Figure 7.1 - List of countries where the Otta seal has been used.....	25

Foreword

As part of its development assistance to a number of mostly developing countries, the Norwegian Public Roads Administration, under the auspices of NORAD, has promoted the use of the Otta seal - an innovative type of bituminous surface treatment with characteristics that are quite different to the more traditional types of surface treatment. The reported experiences of the cost-effective use of the Otta seal in a range of environmental conditions have been very encouraging, particularly where good quality aggregate is not available.

Unfortunately, the lack of information regarding the Otta seal in terms of its properties, design and construction has hampered its more wide-spread use. To rectify this situation, this publication has two main objectives:

- To summarise more than 25 years of experience with the global use of Otta seals and to provide technical evidence and economic justifications for its consideration for use in all countries.
- to provide state-of-the-art information on the provision of the Otta seal surfacing as an economic and practical alternative to more traditional surface treatments.

The publication will provide the required guidance to a wide range of stakeholders including politicians, practitioners, consultants and contractors, as well as material suppliers, donors, road users and, importantly, Road Authority personnel - who may be considering the use of the Otta seal in their countries.

By promoting an innovative approach to the provision of bituminous surface treatments, this publication will undoubtedly lead to a more efficient use of available resources. This will result in direct benefits to many countries and will facilitate socio-economic growth and development and much needed poverty reduction.

This publication also provides a useful list of references on the design, construction and maintenance of Otta seals.

Abstract

Natural gravel materials have traditionally been used for upgrading earth to gravel roads or for regravelling existing gravel roads. However, serious concerns have arisen regarding the continuous use of vast amounts of gravel - a non-renewable, finite resource - which is not only being rapidly depleted in many countries but is also unsustainable in the medium to long term. This has prompted road engineers to consider the use of low-cost bituminous surface treatments on these gravel roads as an alternative to regravelling them in an unsustainable and increasingly costly programme.

One type of surfacing that can provide an economic and practical alternative to traditional surfacings, such as the Chip seal, is the Otta seal. Unfortunately, lack of information regarding this relatively new type of bituminous surfacing has suppressed its more widespread use, despite its excellent performance in a number of countries.

In view of the above, this publication provides state-of-the-art information on the provision of the Otta seal surfacing as an economic and practical alternative to the more traditional bituminous surface treatments. The publication outlines the origin, properties, design and construction of the Otta seal and discusses its implementation impacts and the various factors that contribute to its sustainability. Finally, the paper provides information on the global use of the Otta seal, including two case histories relating to its introduction in eastern and southern Africa.

Acknowledgements

The Rural Transport Thematic Group of the World Bank commissioned this report following an initiative of Ornulf Strom of the Norwegian Agency for Development Cooperation (NORAD). The report is based on work carried out initially in Norway in the early 1960s and subsequently adapted for use in a number of developing regions of the world including eastern and southern Africa, Asia and Australia.

The authors would like to acknowledge the valuable assistance provided by a number of Government organisations that supported the carrying out of trials in their countries and provided staff to participate in the monitoring of these trials. Particular thanks are due to the Governments of Botswana and Kenya where the Otta seal was first pioneered in the 1970s and to the Directors and staff of the Roads Departments in these countries for their open-mindedness in embracing an alternative to the traditional types of bituminous surfacings.

List of Acronyms

AADT	Average Annual Daily Traffic
AC	Asphalt concrete
BS	British Standard
LBM	Labour-Based Methods
LVSr	Low volume sealed road
HIV/AIDS	Human Immune Deficiency Virus/Acquired Immune Deficiency Syndrome
NPRA	Norwegian Public Roads Administration
NRRL	Norwegian Road Research Laboratory
NORAD	Norwegian Agency for Development Cooperation
RED	Road Economic Decision model
SADC	Southern African Development Community
USA	United States of America
vpd	vehicles per day
10% FACT	Ten per cent Fines Aggregate Crushing Value

OVERVIEW AND CONCLUSIONS

Roads Development and Poverty Reduction

Road Transport is the most pervasive mode of transport in most developing countries where it accounts for about 80% of the total trade in goods and services. Unfortunately, despite the substantial investments made in road infrastructure, the cost of road transport services is still inordinately high, especially in rural areas where the majority of the population live and are involved in some form of subsistence agriculture. This has led to international development support and promotion of policies aimed at improving rural accessibility and reducing poverty.

A substantial proportion of the road network in developing countries, typically more than 75%, consists of earth or gravel roads. For many years, gravel has traditionally been used for upgrading earth roads or maintaining existing unsurfaced roads. However, gravel is a “wasting” material and the continued use of this finite, non-renewable resource is not sustainable in the medium to long term. Moreover, the cost of regravelling a relatively large proportion of any country’s road network is often beyond the financial capability of most developing country governments. This has engendered a need for considering the use of alternative low-cost bituminous surfacings which would be more cost effective to use than repeatedly gravelling unsurfaced roads in an unsustainable programme.

Bituminous Surfacings

Various types of bituminous surfacings with differing characteristics and service lives have been developed for application to specific situations depending on such factors as traffic volume, type of pavement and the environment. The more traditional types of surfacing include the following:

- Chip seals
- Slurry seals
- sand Seals

The above surfacings offer many obvious advantages to road users over unsealed roads including a smoother and more comfortable ride, less dust generation and all year passability. The final choice of surfacing should ideally be based on a life-cycle cost analysis in which not only initial construction costs are considered, but also maintenance costs (e.g. resealing, fog spraying, road marking) and vehicle operating costs.

One type of surfacing that has proven to be eminently cost-effective in appropriate situations is the Otta seal.

The Otta seal Surfacing

The Otta seal is a particular type of bituminous surface treatment which was originally developed by the Norwegian Road Research Laboratory (NRRL) in the early 1960s. It derives its name from the location in Norway where it was developed - the Otta Valley.

Although initially intended for use as a temporary surfacing on newly constructed roads, its good performance has led to its adoption as a permanent single or double seal with or without a sand seal cover for both new and existing roads in a variety of traffic situations ranging from light to heavy.

The design of the Otta seal is relatively simple. It relies on an empirical approach that is based on experience in the selection of both an appropriate type of binder and an aggregate application rate. Guidelines are now available to guide practitioners in the design of Otta seals.

The construction of an Otta seal is similar in principle to that of a conventional bituminous surface treatment. However, many of its construction activities can be undertaken using labour-based methods - a major advantage in terms of employment provision.

Characteristics of the Otta seal

Otta seals differ in many respects from traditional bituminous surface treatments. These differences include such factors as aggregate quality, binder type, design, construction, and durability. By virtue of these differences, Otta seals offer a number of important advantages over traditional surface treatments, including:

- an ability to tolerate the use of relatively inferior aggregates, such as screened gravel, rather than crushed rock, without impairment of the performance of the surfacing;
- an enhanced durability that is better able to combat high solar radiation that causes rapid ageing and hardening of the binder and consequent degradation of the surfacing;
- scope for utilising labour-based methods in many aspects of its construction;
- a favourable life-cycle cost-benefit ratio of the order of 50% to 60% of the more commonly used seals, such as the Chip seal.

Impacts and Sustainability of the Otta seal

The introduction of a new type of surfacing, such as the Otta seal, will only be sustainable in the long term if it produces impacts that are acceptable to all stakeholders - an essential prerequisite if progress towards achieving higher developmental goals is to be achieved. The various factors that contribute to developing sustainable implementation of the Otta seal include:

- *Political:* Political support in terms of acceptance of new technology.
- *Social:* Use of employment creation strategies, such as labour-based methods, wherever technically and economically feasible.
- *Institutional:* Adoption of methods of construction that can be easily undertaken by small contractors.
- *Technical:* Use of a wide range of materials with less stringent requirements than that required for traditional seals.

- *Economic:* Lower life-cycle costs than that offered by traditional seals.
- *Financial:* Less demanding maintenance requirements over a longer intervention cycle thereby reducing the financial burden on roads agencies.
- *Environmental:* Reduced depletion of natural gravel resources as well as a reduction in dust levels.

Global Use of the Otta seal

The use of the Otta seal is becoming more wide-spread in a number of countries as more experience is gained in its use. The Otta seal is now used in a number of countries in eastern and southern Africa as well as in Bangladesh and Australia.

Although, the merits of the Otta seal are now fairly well known there is still some resistance to change from the more conventional and in many cases less cost-effective surfacing types. The reasons for this may be many, but the main constraints are probably the change of specifications which puts some of the responsibility on the Client as both the Consultant and the Contractor may be instructed to adopt the Otta seal approach.

The effective dissemination of previously published documents and the holding of workshops involving all the stakeholders in the road construction industry may lead to more widespread use of the Otta seal in developing countries.

Recommendation

In situations where traditional approaches to upgrading earth roads or maintaining unsurfaced roads by continuous gravelling/regravelling are no longer tenable, consideration should be given to the use of the Otta seal as an alternative to the other traditional types of surface treatments. However, a final decision should be made on the basis of a life-cycle cost analysis of the alternative surfacing options.

1. INTRODUCTION

Background

In many developing countries, a substantial proportion of the road network, typically more than 75%, consists of gravel and earth roads. These unpaved roads generally carry relatively light (generally less than 200 vpd) but nationally important traffic and provide access to rural areas where the majority of the population live. Rural communities depend on reliable, year-round road access without which their basic social and economic needs cannot be met. In turn, development and poverty alleviation efforts, often given high priority by national governments and international agencies, would be hampered.

Despite their vital importance, unpaved roads often exhibit various untenable problems: Earth tracks become impassable during the rainy season; gravel wearing courses are continually abraded by traffic and the weather; dust clouds develop in dry conditions and cause health and safety problems; frequent, relatively expensive blading operations by motor grader are required to restore riding quality; and regular regraveling depletes natural occurring gravel - a finite, often scarce, non-renewable resource. Thus, serious concerns have arisen regarding the efficacy of pursuing traditional strategies that are unsustainable in the medium to long term from a financial, resource management and environmental perspective.

The inherent problems of maintaining unpaved roads can be overcome by paving them. However, even when this solution is economically justifiable, it is often not possible to adopt it in most developing countries because of very limited funds. This has prompted road engineers to search for and develop innovative methods of surfacing unpaved roads in order to reduce costs, improve their economic attractiveness and at the same time not impair the quality of the end product. To achieve this goal, consideration often has to be given to the use of relatively inexpensive, locally available materials that may be non-standard or of marginal quality relative to "standard" materials. However, the judicious use of such materials can result in an end product that is "fit for purpose" although it may not satisfy conventional specifications or methods of design, yet still provide an acceptable level of service in a cost-effective manner.

One type of surfacing that can provide an economic and practical alternative to traditional surfacings is the Otta seal. This type of surfacing allows the use of relatively inferior, naturally occurring, unscreened gravels in circumstances where the use of traditional bituminous sprayed surfacings using relatively expensive crushed rock would generally be unaffordable or simply not possible due to the unavailability of such materials.

Purpose and Scope

The Norwegian Agency for Development Cooperation (NORAD) and the World Bank have recognized the potential benefits to be derived from the use of bituminous surfacings, such as the Otta seal, which can provide appropriate, economical and sustainable alternatives to traditional seals. Unfortunately, however, the adoption of the Otta seal is not as widespread as it could be due to a number of factors. These include: lack of awareness of the satisfactory performance of Otta seals; an aversion to the use of "non-standard" surface treatments,

particularly by foreign consultants and contractors who are often unfamiliar with local conditions and, until relatively recently, insufficient documentation on Otta seals.

The main purpose of this publication is to provide state-of-the-art information on the provision of the Otta seal surfacing as an economic and practical alternative to more traditional road surfacings such as Sand seals, Chip seals and Slurry seals. This information is based on the accumulated experience derived from both full scale projects and trial sections undertaken in a number of countries in southern and eastern Africa, Asia and Australia over the past 20 years.

The publication is aimed at a wide range of stakeholders, from politicians to practitioners, including consultants and contractors, as well as material suppliers, donors, road users and, importantly, Road Authority personnel who, in one capacity or another, are involved in the provision of Otta seals.

Structure and Content

The paper is divided into eight chapters as follows:

Chapter 1: (this chapter): Provides a general **Introduction** to the paper including its purpose and scope.

Chapter 2: Contains a review of **Roads, Development and Poverty Reduction** in which the issue of providing and maintaining large unpaved road networks in a sustainable manner using traditional approaches is raised and the case for low-cost sealed roads is advocated.

Chapter 3: Discusses **Bituminous Surfacing** including their role, functions, mechanisms of performance and factors affecting their choice.

Chapter 4: Provides details of the **Otta seal Surfacing** including its design and construction.

Chapter 5: Outlines the **Characteristics of the Otta seal.**

Chapter 6: Discusses **The Impacts and Sustainability of the Otta seal.**

Chapter 7: Highlights the **Global Use of Otta seals** including two case histories of its use.

Chapter 8: Presents the **Conclusions and Recommendations** of the paper.

2. ROADS, DEVELOPMENT AND POVERTY REDUCTION

Road Transport Infrastructure and Development

Transport is central to the social and economic development of any country. Its primary role is to facilitate people's access to goods, services and information to enable them to live economic and socially productive lives. Without adequate transport, physical access to jobs, health, education and other amenities, the quality of life suffers; without physical access to resources and markets, growth stagnates and poverty reduction cannot be sustained.

Of the various modes of transport that prevail in developing countries, road transport is the most pervasive and accounts for about 80% of the total trade in goods and services. Moreover, roads generally provide the only form of access to rural communities where the majority of the population (often in excess of 75%) live and are involved in some form of agriculture for their livelihoods. Without adequate road transport farmers will not produce cash crops for urban populations, will find it difficult to send their children to school or to make use of preventative health care. In emergencies, their sick will often not reach clinics in time. As a result they are likely to remain in physical isolation and trapped in poverty.

Unfortunately, despite the substantial investments made in road infrastructure, the cost of road transport services is still inordinately high, especially in rural areas where a lack of adequate access and mobility still pose important constraints on development and poverty reduction efforts. This has led to international development support and promotion of policies aimed at improving rural accessibility and reducing poverty.

Rural Accessibility and Poverty Reduction

Rural roads constitute a significant proportion of the total road network in most developing countries. In so doing, they contribute significantly to poverty reduction, through the services they provide to the poor and to priority social and economic sectors, and through employment creation and the building of skills and capacities. Thus, the provision of adequate rural road infrastructure can be a powerful ally in a country's attack on poverty and in many countries has become an integral part of public intervention targeted at meeting the basic needs of poor people. However, the contribution of the rural road sector to poverty reduction is not yet optimised and many improvements can still be made to transport policy and strategy.

One intervention that is strongly promoted is with regard to improving accessibility to rural areas in many developing countries where a substantial proportion of the road network, typically more than 75%, consists of gravel and earth roads. These relatively low-volume roads often fulfil a potentially vital socio-economic function, not only by providing access to rural areas where the majority of the population live, but also by connecting the productive agricultural areas to the primary road network.

Sustainability of Gravel Roads

For many years gravelling has been the preferred option for surfacing when upgrading from earth roads. Natural gravel materials are usually excavated from borrow pits or quarries and hauled by trucks to be laid on the previously shaped formation or road surface to a thickness of typically 150 mm to 200 mm to form an “all-weather” running surface.

A gravel road surface can be appropriate and cost effective in certain specific circumstances. These include situations where:

- sufficient quantities of gravel are available that meet the required surfacing specifications;
- haul distances are relatively short;
- longitudinal road gradients are less than about 6%;
- rainfall is low or moderate;
- traffic is relatively low;
- dry season dust generation is not severe;
- finance and resources are going to be available for the necessary on-going periodic re-gravelling and routine maintenance.

However, increasingly, the above suitability criteria are often not met and the practice of managing more than 75% of national road network as gravel roads is being seriously questioned. The major concerns to national governments, development agencies and rural roads agencies over the efficacy of rural road gravelling/re-gravelling may be summarised as follows:

Financial and economic issues

- Gravel is a sacrificial, “wasting” layer that is being rapidly depleted in a number of countries. Gravel loss rates per annum are typically of the order of 30-50 mm, depending on such factors as traffic, climate and terrain. Thus, the uppermost 30-50 mm wearing layer that overlies the 100-120 mm residual gravel support layer can be lost annually while, without regravelling, the entire layer can be lost within 3-5 years!
- The cost of periodic regravelling and routine maintenance of gravel roads can be very high. Regravelling costs are typically of the order of US\$ 5,000 to US\$ 30,000 per km per year depending on such factors as width and thickness of gravel layer, gravel quality, haulage distance, haul conditions, technology used, location, mineral fees, organisational arrangements, etc. In addition, routine maintenance costs related to grading/reshaping, patching and off-carriageway operations are typically of the order of US\$ 2,000 to US\$ 3,000 per km per year. Such costs are often beyond the financial capability of most developing country governments.

Institutional and management issues

- Unpaved roads generate a continuous cycle of deterioration which requires substantial amounts of replacement gravel. In the Southern African Development Community (SADC) region alone, this figure is estimated to be of the order of 150 million cubic metres per annum – an unsustainable activity in the medium to long term.

- The substantial amount of gravel required to maintain unpaved roads in acceptable condition is often beyond the limited capacity of many roads agencies. The result is a continuous cycle of gravel road deterioration resulting in loss of asset value and the creation of an increasing backlog of road maintenance that contributes to high transport costs.

Standards and technology issues

- Imported motorised graders are the traditional equipment for grading and gravelling or regravelling operations. This not only requires considerable financial investment in a high-cost finance environment but also raises very serious problems of ownership and operation of relatively sophisticated equipment. This often results in operational, support and technical problems as well as a local financing burden.
- Very often, spot improvement gravelling may be the optimum solution for unpaved road maintenance. However, because selective gravelling in practice is difficult to achieve, this results in wastage of finite resources.
- The technology of using graders for regravelling purposes is not sustainable in a number of countries where it would be preferable to employ alternative methods of maintaining unpaved roads involving local communities to a greater extent and utilizing using local resources and management more extensively.

Social and environmental issues

- There is a continuous demand for the use of a non-renewable, natural resource which is being seriously depleted in many countries. As a result, haul distances and costs are continually increasing while land take is continuing at an alarming rate. Moreover, borrow-pit rehabilitation can be a costly exercise that is often neglected.
- Dust generation in dry weather causes adverse impacts in terms of being a health hazard for communities living adjacent to the road as well as causing pedestrian, animal and vehicle safety problems related to visibility and overtaking movements. In addition, dust emissions cause damage to crops and natural habitats.
- Gravel roads are often slippery and dangerous in wet weather, especially in steep terrain, causing access problems for communities. They are also susceptible to erosion causing silting of drains and water courses. Chemical treatment options can be hazardous.

The Case for Low - Cost Sealed Roads

For the various reasons cited above, gravel is often not an appropriate or sustainable solution for many road locations in developing countries. Fortunately, there is a range of alternative surfacing and paving options, proven in various countries that could provide appropriate, economical and sustainable alternatives in many instances. Suitability will depend on local circumstances but these alternatives, together with an appropriate use of the available gravel materials, may be cheaper in life-cycle cost terms.

Reduced traffic thresholds for sealing gravel roads

Conventional design and construction methods coupled with conventional cost-benefit analysis result in thresholds for sealing roads at about 200 vpd. However, traditional methods of investment appraisal rely on benefits arising from the reduced costs for motorised road users while, in practice, such benefits tend to be of a social rather than economic nature and the beneficiaries also include non-motorised traffic and pedestrians.

Developments in technology, research and knowledge have created a new platform for a more rational and up-to-date approach to the economics of rural road provision. Improved appraisal methods are increasingly able to capture the social benefits or disbenefits arising from the provision or absence of adequate road infrastructure which should be included in any economic evaluation of rural road projects.

By adopting appraisal methods that are able to capture the non-economic benefits of low-volume road provision (e.g. the Roads Economic Decision (RED) model. [Archando-Callao, 1999] and by promoting the use of local materials and using labour-based approaches and technologies coupled with design approaches that work with the environment, both the initial construction and longer term maintenance demand can be significantly reduced, resulting in lower predicted life-cycle costs than the gravelling option. Indeed, recent research has shown that in some circumstances bitumen sealing of gravel roads is economically justified at traffic levels as low as 40 to 70 vpd [Moruik et al, 1999].

An impetus for change

In view of the above, it is now apparent that the window of opportunity for gravel is gradually closing. Thus, situations conventionally thought to require a gravel surfacing will need to be carefully reconsidered as it may well be more cost-effective to pave the existing gravel road with a low cost seal than to acquire materials for unsealed roads which would require to be repeatedly re-gravelled in an unsustainable programme. Such developments provide a strong impetus for promoting policy change and provision of low-cost bituminous surface treatment technologies that are considered in the next sections of the report.

3. BITUMINOUS SURFACINGS

Functions

Bituminous surfacings are an integral component of paved roads and perform a variety 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 gravel loss, resulting in elimination of costs of replacing gravel, a finite non-renewable resource;
- 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 over its design life. Timely re-surfacing interventions will always be necessary to provide a cost-effective solution.

Types

Various types of bituminous surfacings have been developed for application to specific situations relating to a variety of factors. The challenge is to match the surfacing type to the prevailing circumstances in the most cost-effective and sustainable manner. These types of surfacing are illustrated schematically in Figure 3.1.

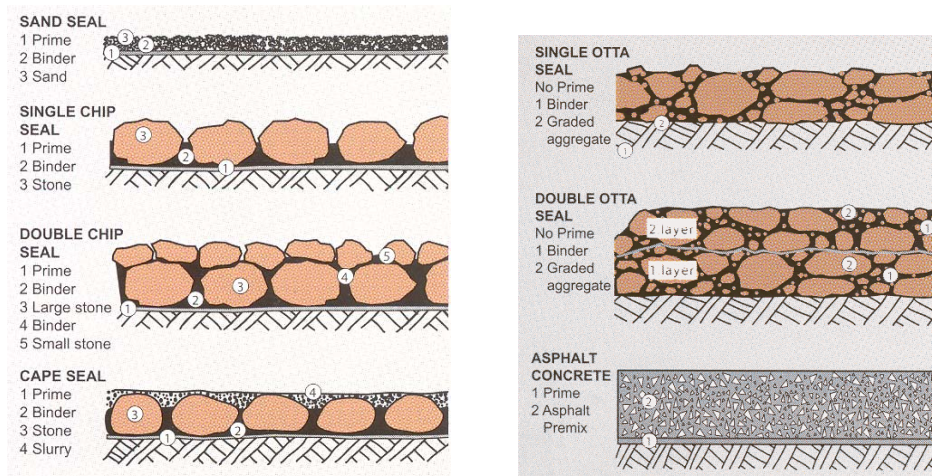


Figure 3.1 - Schematic of common types of bituminous surfacings

Mechanism of Performance under Traffic

The various types of bituminous surfacings (excluding asphalt concrete) illustrated in Figure 3.1 may be placed in one of two categories as regards their mechanism of performance under traffic which is illustrated in Figure 3.2 and summarised below:

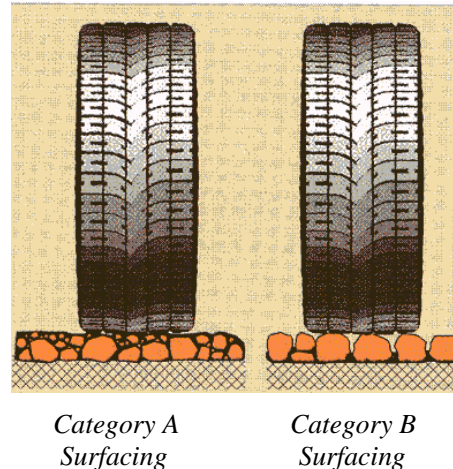


Figure 3.2 - Mechanism of performance of surfacing types

Category A Surfacing: (Sand Seal, Slurry seal, Otta seal)

These seal types rely to varying extents on a combination of mechanical particle interlock and the binding effect of bitumen for their strength, similar to a bituminous premix. Early trafficking and/or heavy rolling is necessary to develop the relatively thick bitumen film around the particles. Within this bitumen/aggregate admixture, the likelihood of stone becoming dislodged and whipped off the road by vehicles is relatively small.

Under trafficking, the seal acts as a stress-dispersing mat comprised of a bitumen/aggregate admixture - a mechanism of performance which is quite different to that of Category B surfacings.

Category B Surfacing: (Chip seal)

This seal type relies on the binder to “glue” the aggregate particles to the base, this being the primary objective of the binder. Where shoulder-to-shoulder contact between the stones occurs, some mechanical interlock is mobilized. Should the bitumen/aggregate bond be broken by traffic or poor adhesion, insufficient material strength, water ingress or numerous other causes, “whip off” of the aggregate by traffic is almost inevitable. Under trafficking, the aggregate is in direct contact with the tyre and requires relatively high resistance to crushing and abrasion to disperse the stresses without distress.

As a result of the difference in the mechanism of performance under traffic between Category A and Category B surfacings, they also differ markedly with respect to such factors as material requirements, design approach, construction features. Examples of these differences are considered in Section 5.

Service Life

The service life of a bituminous surfacing depends on a number of factors including:

- type of surfacing;
- quality of surfacing (aggregate strength, binder durability, construction quality, etc.);
- pavement structure (bearing capacity);
- traffic using the road;
- environment (especially solar radiation);
- road characteristics (geometry).

Table 3.1 presents typical service lives of the various types of bituminous surfacing illustrated in Figure 3.1.

Table 3.1 - Typical range of service lives of bituminous surface treatments

Type of seal	Typical range of service life (years)
Sand seal	2 - 4
Slurry seal	2 - 6
Single Chip seal	4 - 6
Double Sand seal	6 - 9
Double Chip seal	7 - 10
Single Otta seal + Sand seal	8 - 10
Cape seal (13mm + single slurry)	8 - 10
Cape seal (19mm + double slurry)	10 - 14
Double Otta seal	12 - 16

Factors Affecting Choice of Surfacing

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

- traffic volume (volume and type);
- type of pavement (strength, flexural properties);
- characteristics of available materials (e.g. aggregate, binder)
- aggregate type and quality
- environmental considerations (e.g. climate, noise)
- operational factors (e.g. traffic, surface stresses, geometry)
- safety (e.g. surface texture, interference with traffic);
- construction (techniques and contractor/consultant experience)
- maintenance (capacity and reliability)
- economic and financial factors (e.g. funds available, life-cycle costs)

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 activities (re-sealing, fog spraying, road

marking etc.) and vehicle operating costs. One type of surfacing which has proven to be eminently cost-effective for use in appropriate situations and provides a practical alternative to traditional bituminous surfacings is the Otta seal. The details of this relatively new, non-traditional type of seal are presented in subsequent sections of this paper.

4. THE OTTA SEAL SURFACING

Origin and Initial Use

In the early 1960s about 50%, or approximately 40 000 km, of the total public road network in Norway comprised of unpaved gravel roads with low bearing capacity, carrying traffic volumes ranging between 50 - 500 vpd [Thurmann-Moe, 1966]. During the spring thaw period many road sections became impassable to both light and heavy vehicles and, in accordance with prevailing practice, would normally have required to be reconstructed prior to applying a bituminous surfacing. However, the rehabilitation programme progressed slowly due to budgetary and heavy construction plant constraints. This engendered a need for the Norwegian road authorities to develop a method of bituminising the gravel roads to improve their quality at a relatively low cost. Based on economic and technical considerations, the following two main goals had to be achieved:

- the investments should be recovered in a few years through maintenance cost savings only;
- the road user should find the quality and performance of the surface similar to conventional bituminous surfacings.

In order to satisfy the above goals the surfacing should, desirably, comply with the following requirements:

- cheap and easy to construct anywhere in the country;
- utilise locally available natural aggregates;
- impervious to prevent water entry into the water susceptible base material;
- very flexible, durable and easy to maintain.

In 1963 the Norwegian Road Research Laboratory (NRRL) was commissioned to develop a bituminous surface treatment that complied with the requirements listed above [Olsen et al., 1984]. During 1963-65, trials were carried out in the Otta Valley in Norway to develop such a seal. It is from this region that the new seal derived its name - the Otta seal.

The performance of the Otta seal exceeded all expectations. As a result, a type of surfacing that was initially intended for use as a temporary "bituminous maintenance seal" was subsequently also adopted for use on existing and newly constructed bituminous roads carrying both low and medium volumes of traffic. Since its introduction in the early 1960s, the Otta seal has enjoyed extended use from being an economical maintenance seal on gravel roads which, in the event, has also served as a "first generation" bituminous surface treatment.

Description and Types

The Otta seal is essentially 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. After rolling and trafficking, the binder works its way upwards through the aggregate interstices which results in a dense, durable matrix that relies on both mechanical interlock and bitumen binding for its strength - similar to a bituminous premix. This is in contrast to the one or two layers of single-size crushed aggregate that are placed on a relatively thin film of a comparatively hard binder to constitute the more traditional single or double Chip seals [Pinard et al, 1997].

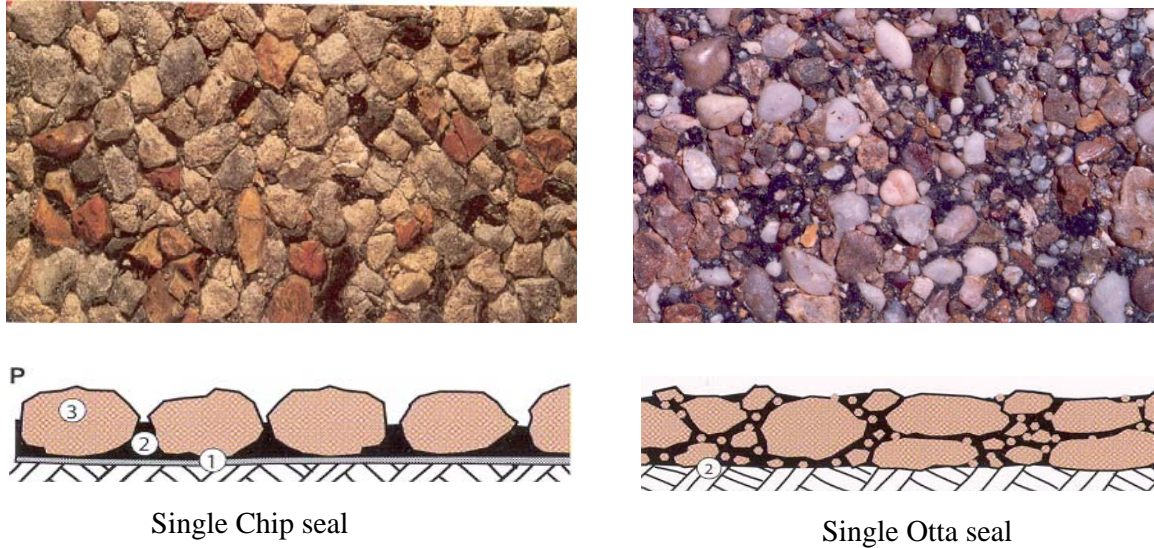


Figure 4.1 - Difference in make-up of single Chip seal and single Otta seal

There are various types of Otta seal 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: - open/medium/dense graded - sand seal/no sand seal cover
2. Double Otta seal: - open/medium/dense graded - sand seal/no sand seal cover

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

The choice of a particular type of Otta seal in relation to traffic level is broadly as indicated in Table 4.1. These recommendations are flexible and will be project dependent.

Table 4.1 - Recommended type of Otta seal in relation to traffic levels

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

Properties

Aggregates

One of the main advantages of an Otta seal is the flexibility it offers in terms of the variety of materials that can be used for producing the graded aggregate. Accordingly, the approach to producing the graded aggregate should be to devise the best way of using whatever source of materials is available in combination with a judicious choice of binder [Overby, 1988].

Both crushed or uncrushed material and a mixture of both can be used for producing graded aggregate for Otta seals. The following are typical examples of the types of gravels/aggregate that have been successfully used [Overby, 1999].

- crushed rock: e.g. Gabbro, Basalt, Silcrete, Sandstone;
- screened/crushed gravel: e.g. Moraine, Coral Stone, Volcanic Ash, Laterite, decomposed Granite, decomposed Basalt;
- river and lake gravels.

The grading of the aggregate should fall within, and should desirably be parallel to, the envelope shown in Figure 4.2. Although the grading envelope is relatively wide, the preferred maximum size is 16mm (19mm can be tolerated for the double Otta seal) and the maximum amount of fines (material passing the 0.075 mm sieve) should preferably not exceed 10%, although fines in excess of 20 % have performed well. The grading of naturally occurring gravel generally falls within the specified envelope, but where there is oversize material it has to be removed by screening. The recommended grading in relation to traffic level is indicated below.

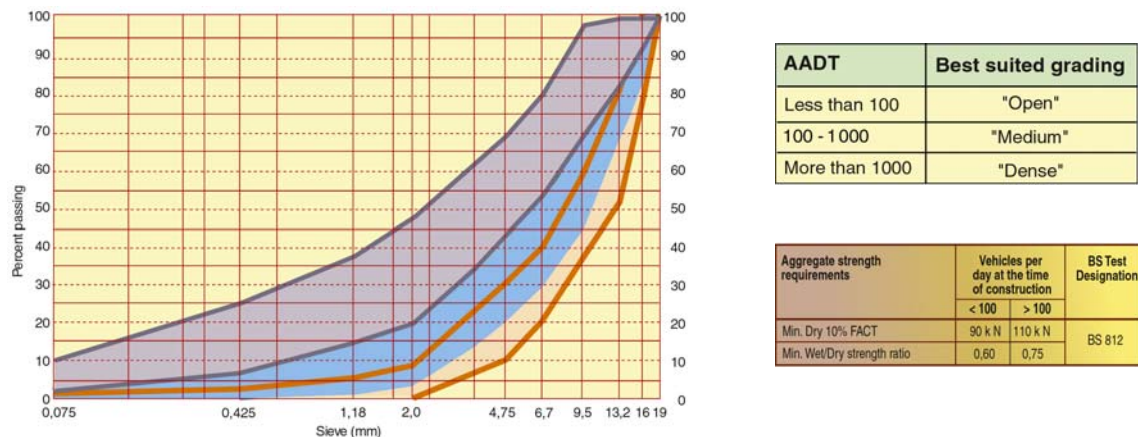


Figure 4.2 - Grading and aggregate strength requirements for an Otta seal

Binders

The type of binder used in an Otta seal can significantly affect its constructability, durability and ultimate performance. It is therefore critically important that a correct choice of binder is made to ensure that the critical function of a complete coating of the mineral aggregate particles, even the fines, is achieved during construction. The range of binders and related viscosities that have been found to be most appropriate for this purpose are as follows:

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

The above types of binders are generally manufactured at refineries from where they can be readily supplied. However, one may also cut back the penetration grade bitumen with power paraffin to the required viscosity range (for details, see to the guideline referenced at the bottom of this page).

Design

Compared to other types of bituminous surface treatments, the design of an Otta seal is relatively simple. It relies on an empirical approach that is based on experience in terms of the selection of both an appropriate type of binder and an aggregate application rate. The factors that influence such a selection include:

- aggregate type and grading;
- binder type (viscosity) and curing time;
- traffic volume and proportion of heavy vehicles;
- porosity of base or condition of old surfacing;
- rolling equipment, capacity and procedure;
- weather conditions during construction.

As a general guide, the following hot spray rates apply for Otta seals.

Table 4.2 - General guide for Otta seal binder spray rates

Traffic level at time of construction (AADT)	Hot spray rates (l/m ²)
< 100	1,8 - 2,2
100 - 500	1,8 - 2,0
> 500	1,6 - 1,8

An adhesion agent is generally used with natural gravels to improve adhesion between the binder and the aggregate. However, the need for such an agent with crushed rock should be determined on the basis of an appropriate adhesion test (e.g. Riedel and Weber).

Aggregate application rates vary between 0,013-0,020 m³/m² and for sand cover seal between 0,010 - 0,012 m³/m². However, in practice the aggregate and sand application rates will very often be increased in order to reduce the risk of bleeding.

Full details of the design and construction of Otta seals may be found in a number of recently produced guidelines including the following:

- Norwegian Public Roads Administration: *Publication No. 93 - A Guide to the Use of Otta seals. 1999.*
- Botswana Roads Department: *Guideline No.1: The Design, Construction and Maintenance of Otta seals. 1999*

Construction

The construction operations for an Otta seal are similar to those of a conventional bituminous surface treatment and involve the spraying of the bituminous binder followed by the spreading of aggregate. However, in contrast to the procedure adopted in the construction of the more traditional surface treatments, priming of the basecourse is generally not required prior to the application of the binder for the first layer of an Otta seal, except in the case of stabilised and calcareous bases. In order to bind the dust on the top of the base, and also open the top base upper pores, it is essential to dampen the base water prior to spraying the binder.

During construction of an Otta seal, the following points should be noted:

- The aggregates should preferably be applied by self-propelled or truck mounted chip spreaders. However, it is also feasible to spread the aggregate by hand using labour, both from a reversing truck or from staggered aggregate stockpiles along the road side. [Overby, 1982 and 1996].
- The use of pneumatic tyred rollers (minimum weight 12 tons) is essential in view of their ability to knead the binder upwards through the aggregate particle interstices. The more intensive the rolling that is applied to the aggregate the better will be the quality of the Otta seal. In the absence of pneumatic rollers, compaction can be successfully carried out by the use of loaded trucks following a set rolling pattern covering the entire surfaced area.
- The road should be opened to traffic immediately after rolling is completed as this will assist in the further compaction of the seal. In order to avoid whip off of the aggregate during the first few weeks after opening the road to traffic, a maximum speed limit of 40 - 50 km/hour should be observed.
- The initial occurrence of fatty spots should not be cause for concern and can be rectified by blinding with fine aggregate which is rolled into the bitumen.
- A minimum period of 8 - 12 weeks should elapse between the construction of the first and the second layers.

Immediate Post-Construction Care

The immediate post-construction care of an Otta seal is important to its longer-term performance and requires careful attention. Such after-care includes additional rolling and brooming back the aggregate that has been dislodged by traffic into the wheel tracks. This ensures that maximum amount 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.

Three to four weeks after construction, excess aggregate (the amount of which would depend on the amount of rolling carried out during construction) can be swept off the road surface and the traffic speed restrictions can be lifted. However, if natural gravel with a fairly high fines content is used the after care period of the seal should be prolonged [Botswana Roads Department, 1999].

Use of Labour-based methods

Otta seals provide wide scope for their construction utilising labour based methods (LBM) and, in so doing, create much need employment. Although a few activities, such as the rolling of the surfacing aggregate, will require the use of mechanical plant, the majority of activities can be carried out using LBM. These include

- digging and screening aggregate by hand;
- loading screened aggregate for transport to site;
- spreading screened aggregate directly on the sprayed bitumen;
- off-loading screened aggregate onto heaps placed along the road;
- spreading screened aggregate from heaps placed along the road onto the sprayed bitumen;
- removing oversize aggregate from the surfacing;
- pulling the drag broom in order to improve the distribution of aggregate;
- brooming back dislodged aggregate into the exposed areas;
- brooming off all excess aggregate.

For comparison Table 4.1 shows the labour friendliness of various surfacing types.

Table 4.1 - Labour friendliness of various surfacing types

		‘Friendliness’ for labour-based methods				
		<i>(Good – Moderate – Poor)</i>				
		Chip seal¹	Otta seal²	Sand Seal	Slurry³	AC⁴
Production of aggregate	Quality	Poor	Good	Good	Good	Poor
	Output	Poor	Good	Good	Poor	Poor
Construction of surfacing	Quality	Moderate	Good	Good	Good	Poor
	Output	Good	Good	Good	Moderate	Poor
1) Hand-crushing of aggregate for surface dressing tends to produce flaky chippings with some rock types. 2) Oversize and fines can be removed by hand screening of natural gravel aggregate for use with Otta seals. 3) Output of aggregate production for slurry (crusher dust) depends entirely on availability on the commercial market. 4) Although included for comparison with other seal types, AC would not normally be used on a LVSR.						

Maintenance and Reseals

The repair and resealing of any localised surface defects of an Otta seal surfacing are similar to that undertaken for any other sprayed type of surfacing.

The use of Otta seals as reseals does not differ from other sprayed types of bituminous reseals that are commonly used. Accordingly, the preparatory work necessary for a reseal using a conventional Chip seal is also required for Otta seals. However, in contrast to traditional 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.

Due to the relatively flexible nature of the Otta seal, it is also well suited as a reseal for roads that are extensively cracked or patched, but are still structurally sound.

5. CHARACTERISTICS OF THE OTTA SEAL

Relative Differences between Otta seals and Traditional Seals

As indicated in Section 3 and summarised in Table 5.1, the Otta seal differs in many respects from traditional bituminous surface treatments.

Table 5.1 - Relative differences between Otta seals and traditional seals

Parameter	Category A (Otta seal)	Category B (Chip seal)
Aggregate quality	Relaxed requirements for: <ul style="list-style-type: none"> - strength - grading - particle shape - binder adhesion - dust content Maximises the 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 inappropriate.
Binder type	Relatively soft (low viscosity) binders are required: 150/200 pen. grade or MC3000 or MC800 cutback bitumen.	Relatively hard (high viscosity) binders are required for aggregate retention: 80/100 pen. grade under hot conditions.
Design	Empirical approach. Relies on guideline and trial design on site. Amenable to design changes during construction.	Rational approach. Relies on confirmatory trial on site. Not easily amenable to design changes during construction.
Construction	Relatively little sensitivity to standards of workmanship. Labour-based approaches relatively easy to adopt if desired.	Sensitive to standards of workmanship. Labour-based approaches relatively difficult to adopt if desired.
Durability of seal	Enhanced durability due to use of relatively soft binders and a close-textured surface.	Reduced durability due to use of relatively hard binders and open-textured surface.
Aesthetics	Exhibits a non-uniform, patchy appearance which improves with trafficking.	Exhibits a very uniform, even appearance when well constructed.
Skid resistance in wet weather	Initially exhibits relatively low skid resistance which tends to be reduced (worsen) with trafficking.	Initially exhibits relatively high skid resistance which tends to be reduced (worsen) with trafficking.

By virtue of the relative differences between Otta seals and traditional seals, the Otta seals exhibit a number of advantages and disadvantages which are discussed at the end of this Section.

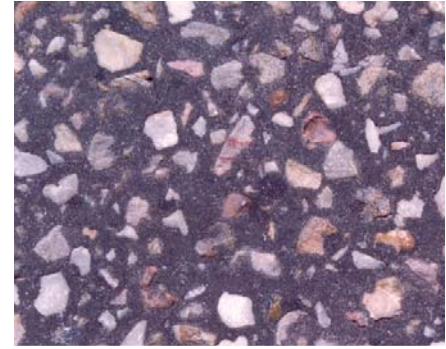
Performance Characteristics

As is the case with most types of bituminous surfacings, the performance of an Otta seal, in terms of its service life, depends on a number of factors including, significantly:

- type of Otta seal (particularly as regards its durability);
- bearing capacity of the pavement;
- traffic volumes;
- prevailing environment.

Durability

The texture of the Otta seal has been found to play a critical role in its performance which is related to the rate at which the binder hardens and the manner in which the surfacing eventually fails at the end of its service life. Thus, an Otta seal constructed with a dense, close-textured grading tends to be far less susceptible to solar radiation and consequent hardening of the binder. As a result, it is able to provide a more durable, longer-lasting surfacing than a conventional Chip seal which has a more open-textured grading.



Example of a durable bituminous surface treatment - a single Otta seal with Sand seal cover exhibiting a dense, close-textured surface.

Bleeding

Bleeding of Otta seals is more easily cured by blinding with sand than is the case with conventional seals because of the use of a relatively softer binder in their construction. The soft binder tends to fairly readily coat the fine sand particles in a manner that is not possible with the harder binders used in conventional seals.

Economic Characteristics

Cost-effectiveness

As indicated in Figure 5.1, a life-cycle cost comparison between a single Otta seal and a commonly used double Chip seal reveals a significant cost benefit in favour of the Otta seal. This advantage is derived largely as a result of the following factors:

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

In view of the above, a major benefit of using Otta seals is that for a given budget, a greater length of paved roads can be constructed compared to the conventional Chip seal.

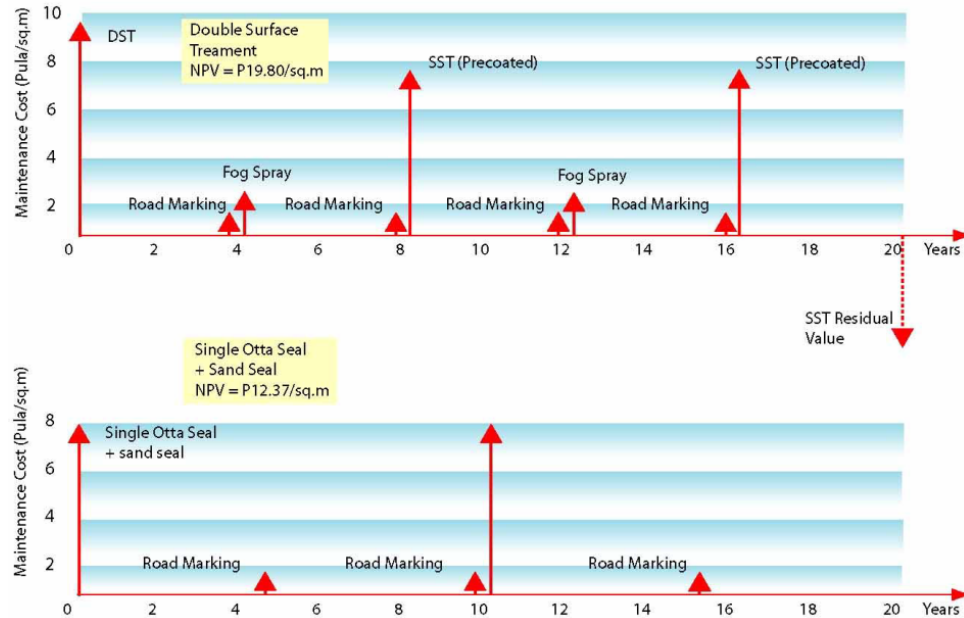


Figure 5.1 - Life cycle cost comparison between a single Otta seal + Sand Seal cover and a double Chip seal

Relative Advantages and Disadvantages

Advantages:

The main advantages offered by the Otta seal surfacing are:

- they are particularly suited for road projects in remote areas where crushing facilities are unavailable (or prohibitively expensive to establish) and use can be made of locally available screened gravel;
- where crushing facilities are available, a greater proportion of the crushed material is utilised;
- they are able to tolerate the use of lower grade aggregates than conventional seals without impairment of the performance of the surfacing;
- they provide a flexible and durable surfacing which is more tolerant of the higher pavement deflections to be expected on low-volume roads constructed with low-grade materials;
- construction faults due to over application of binder or bitumen are less of a problem than with conventional seals;
- contractor capacity and maintenance capability may be low and workmanship may be of indifferent quality.

- The enhanced durability of the surfacing is better able to combat high solar radiation which causes rapid ageing and hardening of the binder and ultimate degradation of the surfacing.
- Is labour-based friendly and offers scope for employment in many aspects of its construction.

Disadvantages

The main disadvantages of the Otta seal are:

- The need to cater contractually for the post-construction “after care” of the seal.
- The use of relatively higher binder and aggregate application rates compared with that required for conventional seals.
- The need for experienced site staff to make adjustments to the nominal design during construction to cater for changes, for example, in aggregate grading or climatic conditions (To varying extents, this is required for all types of surface treatments and is not specific to the Otta seal).

6. IMPACTS AND SUSTAINABILITY OF THE OTTA SEAL

General

The introduction of a new type of surfacing, such as the Otta seal, will only be sustainable in the long term if the impacts that it produces are acceptable to all stakeholders - an essential prerequisite if progress towards achieving higher developmental goals is to be made. Figure 6.1 illustrates the various factors that contribute to developing sustainable implementation of the Otta seal which are discussed further below.

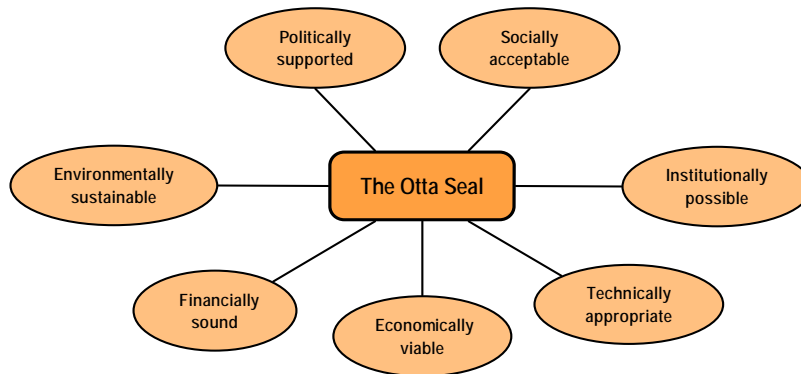


Figure 6.1 - Elements of sustainability of the Otta seal

Political

Political support is always an essential requirement for sustainability in the introduction of any new technology as there is always a tendency to avoid perceived risk and to favour conventional methods and conventional technical solutions. In many developing countries, the political perception of a “good” standard of road surfacing is often perceived as one that has been used in the country traditionally. Thus, asphalt concrete or Chip seals are often the preferred type of surfacing. In contrast, despite its satisfactory, cost-effective performance, the Otta seal is sometimes viewed as a “cheap” seal. Thus, some countries have embraced the technology while others have resisted it. There is therefore a need to continuously engage in dialogue with political and public stakeholders in order to promote the introduction of new technologies such as the Otta seal.

Socio-economic

The socio-economic impacts realised through the introduction of the Otta seal are related primarily to its suitability for construction using labour-based methods which have been described in Section 5. The benefits of adopting such methods include a major contribution to the national objectives of employment creation, poverty reduction and economic growth. More specifically, the direct project-related benefits that enhance the sustainability of the Otta seal include the following:

- Job creation in rural areas where other means of formal employment are either very limited or, in many cases, simply not available;
- Community involvement and a sense of ownership of the infrastructure engendering a greater likelihood of their participation in the subsequent maintenance of the roads;
- Elimination of gender biases by providing opportunities for women to increase their contribution to the economy;
- Injection of money into the local economy leading to economic empowerment and poverty alleviation, especially for rural communities;
- Development of local skills which can serve as a spring board for small-scale local contracting industry with follow-up opportunities for road maintenance and a related contribution to sustainable rural livelihoods.

Typical socio-economic impacts: Based on a socio-economic impact study carried out in a number of rural communities in Botswana [Education Consultants (Pty) Ltd, 2004], the following examples illustrate typical socio-economic impacts resulting from the construction of Otta seals utilising labour-based methods:

- In general terms, approximately 35% of the total contract sum is paid as wages to the labourers, compared to 15% on equipment-based projects.
- A significant number of households in each community derived cash earnings from the project. The resulting injection of earnings into the community created casual employment opportunities for a significant number of people who would otherwise have been unemployed.
- The main use of earnings by households was on meeting basic needs – buying food, household items and clothing. Female-headed households and some male-headed households used earnings to pay school fees (including arrears) and school uniforms.
- Earnings from the project were sufficient to enable households to “invest” in resources that have a medium to long-term benefit, including upgrading of plots or houses and development of small businesses, in some cases creating additional jobs.
- Community leaders reported that the project had a positive impact on the community. More households were able to pay school fees, children attending school were better cared for, as were patients in the HIV/AIDS care programme and, moreover, there was an all-round improvement in quality of life in the communities.

Institutional

There is a growing trend in many developing countries towards the commercialisation of the roads sector and the outsourcing of construction and maintenance activities to the private sector. Because the Otta seal is relatively easy to construct (once the basic concepts are understood), it is an appropriate type of construction activity that lends itself to the promotion of small-scale enterprises and capacity building in the construction industry. The transfer of such activities to the private sector would considerably ease institutional burdens on road authorities and communities and enhance the sustainability of the Otta seal.

Technical

The technical impacts of the Otta seal and its sustainability are related mostly to the technology of the construction process which may be summarised as follows:

- allows the adoption of strategies that maximise the use of local resources and utilise technologies that create employment;
- uses a wider range of local materials for which there are less stringent requirements than other commonly used surfacings such as the Chip seal;
- is relatively insensitive to standards of workmanship and very amenable to the use of labour-based methods that provide the potential for creating employment in a productive manner;
- is appropriate for use by small contractors and in rural environments utilising construction techniques that suit small contractors with limited capital budgets.

Economic and Financial

As a result of the lower initial construction costs (typically +/- 20%), less frequent maintenance interventions and longer life, the life cycle costs of an Otta seal in comparison with the traditional and commonly used Chip seal, is typically of the order of about 50% - 60% (ref. Section 4). Thus, for a given budget, it would be possible to construct a much greater kilometrage of Otta seal surfacings than would be the case with the more traditional Chip seals. The impacts of this benefit which would enhance the sustainability of the Otta Seal include the following:

- rural communities are able to enjoy the many benefits of a sealed road sooner rather than later as a result of governments' ability to provide a greater kilometrage of roads for a given budget;
- as a result of the above, more rapid integration of the rural population of the country living in remote areas into the mainstream of the country's economic and social life;
- increased mobility for the rural populations through the development of passenger-carrying rural transport services with easier access to essential services such as health, education and administrative services.

The major financial impact of the Otta seal is due to its relatively less demanding maintenance requirements over a longer intervention cycle. This would considerably ease the financial and institutional burden on roads agencies and communities - a burden that has resulted in a backlog of road maintenance and resulting poor road conditions in many developing countries.

Environmental

The significant beneficial impact of being able to provide low-cost sealed roads (whether they be Otta seals or other types of seals) rather than to continuously use naturally occurring gravels in an unsustainable regravelling programme, is a reduction in the rate of environmental degradation associated with depletion of scarce, non-renewable resource. This issue has become critically important as in many areas local gravel deposits are non-existent or are not accessible because they are under farm land or worked out, leading to extremely expensive hauls of up to 50 km and more.

Another significant benefit arising from the provision of sealed roads is a reduction in dust levels and related decrease in health problems in villages, increase in traffic safety and reduced adverse impacts on crops adjacent to roads.

7. GLOBAL USE OF THE OTTA SEAL

Introduction of Innovative Technology

The Otta seal is an example of innovative technology in that it presents a new concept in surfacing technology that differs quite fundamentally from the more traditional approaches to surfacing design. It has been field tested and successfully applied in a number of countries and under a variety of conditions. However, the technology is still not fully understood by practitioners because it does not comply with conventional thinking on road surfacings, and there is still some uncertainty regarding its acceptance as a standard type of surfacing. Nevertheless, as indicated below, the use of the Otta seal is becoming more widespread as more and more experience is gained in its use. As discussed below, in meeting the challenges of introducing a new technology, there is a need to engender a greater awareness in decision-makers as to the many potential benefits to be derived from using the Otta seal.

Meeting the Challenges

One of the most effective means of creating awareness amongst stakeholders about the Otta seal is by ensuring that reliable, easily accessible information is available to them in the form of guidelines, reports, technical papers, etc. To this end, the following guidelines have been produced:

- Norwegian Public Roads Administration: *Publication No. 93 – A Guide to the Use of Otta seals. 1999.*
- Botswana Roads Department: *Guideline No.1: The Design, Construction and Maintenance of Otta seals. 1999*

The Otta seal concept is also included in the Pavement and Materials Design Manual (1999), and the Standard Specifications for Road Works (2000), Ministry of Works, Tanzania.

Use of the Otta seal

Figure 7.1 shows various countries where the Otta seal has been used whilst Table 7.2 shows the length of Otta seal surfacings used in these countries.

Figure 7.1 - Countries where the Otta seal has been used



Table 7.1 - Length of Otta seals constructed in various countries (as per 2007)

Country	Length (km)
Norway	12 000*
Sweden	4 000
Iceland	2 000
Kenya	500
Botswana	2 400
Zimbabwe	80
South Africa	30 +/-
Bangladesh	20 +/-
Australia	2.2 (two trials)
Namibia	Trials
Nepal	Trials
Tanzania	100 +/-
Chile	100 +/-
Ghana	20 +/-

* Due to overlaying/strengthening operations, the number of kilometres of Otta seals has been reduced to 3,500 km in 2007.

The Future of the Otta seal

Adoption of new ideas often requires a paradigm shift in thinking with regard to the old, tried and proven way of doing things. Until this bold shift occurs, there is often a tendency to suppress the introduction of new technology. In this context, the future direction for the more widespread use of Otta seals will depend largely on the implementers of policy - the Road Authorities, the Donor community and Consultants/Contractors.

Although, the merits of the Otta seal are fairly well known in east and southern Africa there is still a resistance to change from the more conventional and in many cases less cost-effective surfacing types. The reasons for this may be many, but the main constraints are probably the change of specifications which puts some of the responsibility on the Client as both the Consultant and the Contractor may be instructed to adopt the Otta seal approach. However, the effective dissemination of previously published documents and the holding of workshops involving all the stakeholders in the road construction industry should lead to more widespread acceptance and use of the Otta seal surfacing.

Case Histories

In the late 1970s NORAD was involved in two major road assistance projects in Africa (Kenya and Botswana). At that time there was strong resistance to change the standards that had been used traditionally for the past 30 years - standards that had been imported from USA or Europe. The use of these standards was generally inappropriate and costly to apply in a local environment where climate, traffic and materials differed so vastly from the environment from which the standards had been imported.

Introductory projects

The following introductory projects in both Kenya and Botswana were undertaken in an environment in which the key stakeholders – the national governments and the donor - were both determined to reconsider the efficacy of adopting traditional approaches to low volume road provision and to adopt new methods which offered the potential for significant cost savings.

In Kenya, the 255 km road between Marich Pass to Lodwar - Kolakol (constructed between 1978-85), which is located in the northern part of Kenya, in the Turkana province, was initially constructed as a gravel road. However, due to the severe climate, indifferent material quality and lack of water for compaction and subsequent maintenance purposes, the road deteriorated rapidly. As a result, it had to be reconstructed to a bituminous standard. Various trials using different surfacing types were investigated and the Otta seal was found to be the best technical and also the most cost-effective solution, due in large part to the possibility of using as-dug gravel in the surfacing.

After 15 years in service (to 1995) the Otta seal surfacing was still performing well. However, thereafter, deterioration started to occur and by 2004 most of the road had practically “disappeared” due to take lack of maintenance coupled with use of the road by very heavily loaded vehicles carrying food aid to Sudan. Nonetheless, the last 70 km of the road towards Lodwar was still in good condition. This section had been re-sealed which was not the case for rest of the road.

However, despite the successful use of the Otta seal on the Turkana road, this type of surface treatment was not adopted on other road projects, due largely to the inherent resistance to change that is so often prevalent in public sector organisations.

Botswana: In the 1970's, earth/sand and gravel roads constituted most of the rudimentary road network of Botswana. These roads carried very light but nationally important traffic, generally less than 200 vehicles per day, over vast distances of the country. A common characteristic of many of these unpaved roads is that they traverse the semi-arid, Kalahari Desert regions of the country where their proper maintenance was nearly impossible due to lack of water and suitable wearing course materials. Furthermore, the extraction of the local gravel materials and abstraction of groundwater for the purpose of attempting to maintain such roads in reasonable condition was leading to a gradual depletion of gravel sources and to a severe degradation of the environment.

As a result of the very rough and dusty road surface conditions arising from the use of generally unsuitable gravel wearing course materials, vehicle operating costs were inordinately high and the type of vehicles which could be used for transportation of goods and provision of administrative and extension services between eastern and western Botswana was severely restricted.

In recognition of the social and economic importance of rural roads in the remote areas of Botswana, the Government, with the assistance of NORAD, initiated a Rural Roads programme in 1973 which was aimed at upgrading mostly earth/sand roads to gravel standard.

However, due to the scarcity of suitable wearing gravels and the resulting inordinately high maintenance costs, it soon became apparent that some form of low cost bituminous surfacing utilising the locally available, non-standard, marginal aggregates was required. This requirement triggered the introduction of the Otta seal surfacing in Botswana in 1978, initially on a pilot scale basis, on the Oodi-Modipane road. The overwhelming proven success of the Otta seal surfacing in the late 1970's led to its subsequent wide-scale adoption on most rural roads in Botswana [Overby, 1983].

The road authorities in Botswana adopted the Otta seal surfacing that was first constructed using in-house units. However, in 1997 the first Otta seal was used on a normal tendered contract using a private contractor and supervising consultant.

By 2007, more than 2400 km of roads, including some re-sealing works, have been surfaced using the Otta seal (in-house 1100 km, contractors 1300 km). This accounts for about one third of the total paved road network. A number of these Otta seal surfacings have been in service for more than 14 years without any re-sealing interventions.

For Botswana, the annual cost savings derived from using the Otta seal (with sand seal cover) rather than the traditional double Chip seal) on 3000 km of main and secondary roads are conservatively estimated at about US\$ 7.5 million [Pinard et al, 1999].

8. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. For a variety of reasons, including the continued depletion of a diminishing, non-renewable resource, the use of gravel for upgrading earth roads or gravelling/regravelling existing unpaved roads is becoming increasingly unsustainable.
2. The use of appropriate appraisal methods that are able to capture the full range of social and economic benefits, coupled with technologies that maximise the use of local materials, can result in lower predicted life-cycle costs than the gravelling option.
3. There is now a strong motivation for adopting low-cost sealing strategies rather than persevering with unsustainable and often non-cost-effective maintenance programmes involving repeated regravelling of unsurfaced roads.
4. There is a range of alternative bituminous surfacing options that can provide appropriate, economical and sustainable alternatives to the gravelling option. One such alternative is the Otta seal.
5. The Otta seal, a graded aggregate seal in comparison to the more traditional single size aggregate used in a Chip seal, is a type of bituminous surface treatment that, in appropriate circumstances, can provide a practical and economic alternative to the more traditional type of seals.
6. The main advantages of the Otta seal over other types of bituminous surfacings include:
 - an ability to tolerate the use of relatively inferior aggregates, such as screened gravel, rather than crushed rock, without impairment of the performance of the surfacing;
 - an enhanced durability that is better able to combat high solar radiation that causes rapid ageing and hardening of the binder and consequent degradation of the surfacing;
 - scope for utilising labour-based methods in many aspects of its construction;
 - a favourable life-cycle cost-benefit ratio of the order of 50% to 60% of the more commonly used seals, such as the Chip seal.
7. The use of the Otta seal extends to a number of developing countries, particularly in eastern and southern Africa, where its use is becoming more wide-spread as more experience is gained in its design, construction and maintenance.

Recommendation

In situations where traditional approaches to upgrading earth roads or maintaining unsurfaced roads by continuous gravelling/regravelling are no longer tenable, consideration should be

given to the use of the Otta seal as an alternative to the other traditional types of seals. However, a final decision should be made on the basis of a life-cycle cost analysis of the alternative options.

9. APPENDICES

Photographs showing various Otta seal surfacings, including close-up photographs



Photo. 1a and 1b.

Botswana 2002. Maun - Sehitwa road. Constructed in 1990 – 1993 and surfaced by a single Otta seal and a Kalahari sand cover seal. Resealed in 2001 with a single Otta seal covered by a Kalahari sand cover seal. Example of a well constructed 16 mm max. size single Otta seal as a reseal. Exhibiting a dense, close-textured, relatively uniform, bitumen/aggregate matrix.

Binder and aggregate type/application rates:

Otta seal: 150/200 pen. bitumen @ 1.60 l/m²; Sand cover seal @ 0.70 l/m²; Partly crushed alluvial gravel consisting of quartzite, silcrete and hard calcrete nodules.



Photo. 2a and 2b.

Botswana 2002. Palapye - Martin Drift road. Constructed in 1998 – 1999 and surfaced with a double Otta seal. Example of a well constructed 19 mm max. size double Otta seal Exhibiting a dense, close-textured, with a uniform, bitumen/aggregate matrix.

Binder and aggregate type/application rates:

Otta seal: 150/200 pen. bitumen @ 1.80 and 1.60 l/m², first and second seal, respectively. Aggregate used, crushed granite.



Photo. 3a and b.

Kenya 2004 Kwale - road, Mombasa area. Constructed in 1995 and surfaced with a single Otta seal. Example of a well constructed 19 mm max. size single Otta seal Exhibiting a dense, close-textured, with a uniform, bitumen/aggregate matrix.

Binder and aggregate type/application rates:

Otta seal: MC 3000 @ 1.80. Aggregate used crushed lime stone.

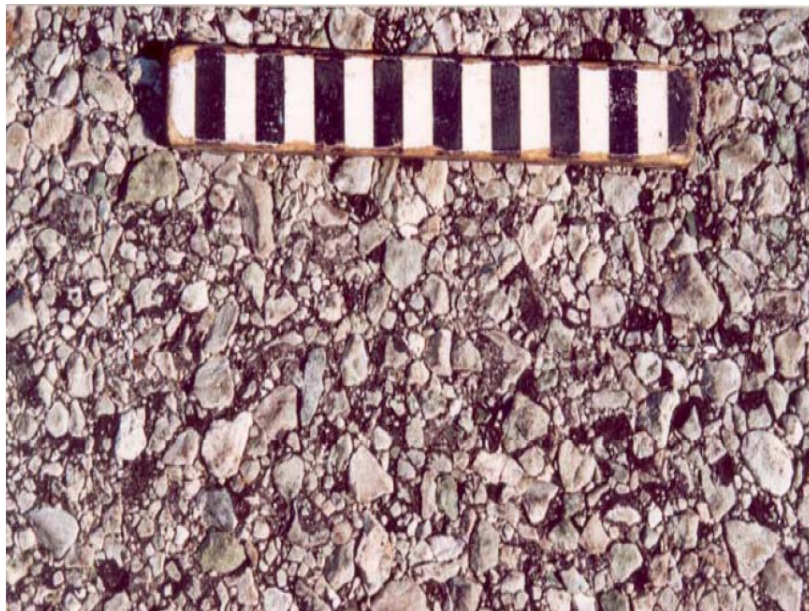


Photo. 4a and 2b.

Botswana 2005. Rakops - Khumaga road, constructed in 2000. Example of a well constructed 19 mm max. size double Otta seal and 6.7 mm sand cover seal surfacing exhibiting a dense, close-textured, relatively uniform, bitumen/aggregate matrix.

Binder and aggregate type/application rates:

Prime: MC 30 @ 1.0 l/m²; Otta seal: MC 3000 @ 1.70 l/m²; Sand/crusher dust seal: MC 3000 @ 0.60 l/m². Duomene-T, an anti-stripping agent, was added to the binder @ 0.8% by weight. Aggregate used in Otta seal crushed silcrete. Aggregate used in sand cover seal crusher dust from silcrete.



Photo. 5a and 2b.

Botswana 2005. Boatile - Mmankgodi constructed in 2000. Example of a well constructed 19 mm max. size single Otta seal and 6.7 mm river sand cover seal surfacing exhibiting a dense, close-textured, relatively uniform, premix-like bitumen/ aggregate matrix.

Binder and aggregate type/application rates:

Prime: MC 30 @ 0.8 l/m²; Otta seal: MC 3000 @ 1.80 l/m²; Sand cover seal: MC 3000 @ 0.70 l/m². Aggregate used in Otta seal crushed granite. Aggregate used in sand cover seal river sand < 7.0 mm.

10. BIBLIOGRAPHY

- Archondo-Callao, R. (1999). *Roads Economic Decision Model (RED) for Economic Evaluation of Low-Volume Roads*. Sub-Saharan Transport Policy Program Technical Note No. 18. World Bank, Africa Regional Office, Washington, D.C.
- Education Consultants (Pty) Ltd.(2004). *Socio-Economic Impact Study: Labour-based Road maintenance Demonstration project*. Final report.
- Hansen, E. K., Refsdal, G., Thurmann - Moe, T. 1980. *Surfacing for Low Volume Roads in semi arid areas*. RF 5th African Highway Conference. Nairobi.
- Mariki, DJJ, Shila EW, Mataka, MO and Overby,C. (1995). *Report on Performance of Otta seals in Kenya*. Ministry of Works, Transport and Communications, Tanzania.
- Ministry of Works, Tanzania (1999). *Pavement and Materials Design Manual*. Dar es Salaam.
- Morusuik, G, Gourley, C.S, Toole T and Hine, JL. 1999). *Whole Life Performance of Low Volume Sealed Roads in Southern Africa*. TRL Annual Report.
- Overby, C. (1982). *Material and Pavement Design for Sealed Low Traffic Roads in Botswana*. Norwegian Road Research Laboratory. Report no. 1042, Oslo.
- Overby, C. (1983). *The Use of Low Quality Calcrete under a bituminous Seal in the Kalahari Region*. XVII PIARC Congress, Sydney.
- Overby, C. (1996). *Sprayed Sealing Guide, Otta seals in Bangladesh*. Norwegian Road Research Laboratory, Project N - 009A, Report no.1, Oslo.
- Overby, C. (1998). *Otta seal - A Durable and Cost-effective Global Solution for Low-volume Sealed Roads*. 9th REAAA Conference, Wellington.
- Overby, C. (1999). *Personal communication*. KwaZulu Natal, Road Authorities and CSIR. Pretoria.
- Overby, C. (1999) *A Guide to the Use of Otta seals*. Publication no. 93, Norwegian Public Roads Administration, Oslo.
- Pinard, M I and Overby, C. (1999) *A note on the impact of using the Otta seal surfacing on the socio-economic development of Botswana*. Gaborone.
- Pinard, MI and Obika, B. (1997) *Optimal use of Marginal Materials for Achieving Cost-effective Surfacing on Low-volume roads in Developing Countries*. XIII IRF World Meeting, Toronto.

Roads Department, Botswana (1999). *Guideline no. 1, The Design, Construction and Maintenance of Otta seals*. Gaborone.

Roads Department, Botswana (1999). *Addendum to Guideline no. 1, The Design, Construction and Maintenance of Otta seals*. Gaborone.

Thurman - Moe, T. (1966). *Billig ekperiment lagt i Roedeberg og Otta dalen sommeren 1966*. Internal report A2/66. Veglaboratoriet (in Norwegian).

