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Bituminous bases and surfacings for low-cost roads in the tropics

by

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TRANSPORT and ROAD RESEARCH LABORATORY
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BITUMINOUS BASES AND SURFACINGS FOR LOW-COST ROADS IN THE TROPICS

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Much of the accumulated knowledge gained from the construction of roads over the last 150 years relates to the use of mechanically stable roadmaking materials such as crushed rock. These materials are not always available, particularly in the remoter parts of many developing countries, but in recent years the development of the technique of soil stabilisation provides practical alternative roadmaking materials in such situations.

The scarcity of aggregates in parts of the Middle East, coupled with the abundance of oil products and the generally arid climate, has encouraged the use of bituminous stabilisation for road construction in the region. Some of the earliest examples of bituminous stabilisation are found in the Middle East, roads consisting of thin sand-bitumen surfacings overlying compacted sand that date from the early 1930's when vehicle axle loads were relatively light.

In the 1940s, as the weight and volume of traffic increased dramatically in the industrialised countries, the need for the structural design of road pavements became widely recognised. The pavement design methods developed at this time related to the roadmaking materials in common use in North America and Europe, and in general they were inappropriate for many of the roadmaking materials available in tropical countries. For example very little guidance on the use of sand-bitumen as a road base material was available until many years later when tentative test methods and design criteria were proposed.

In 1960 the Transport and Road Research Laboratory (or the Road Research Laboratory as it was then known) participated in experimental full-scale road trials in Northern Nigeria with the object of improving knowledge about the appropriate design criteria for light and medium trafficked sand-bitumen roads in tropical climates. The Report describes the conclusions drawn from this experiment and from subsequent research and discusses different methods of constructing sand-bitumen road bases.

Bituminous surfacings range from surface dressing to premixed materials; the latter are not always necessary nor the most appropriate choice. This is especially true of areas in which suitable materials are in short supply and/or in which it is predictable that traffic will not be such as to require a high quality surfacing, at least in the early life of the road. The Report discusses surface dressing, which is important both as an initial running surface on new bases and as a maintenance treatment. Maintenance, which is often neglected, relies extensively on bituminous materials and their effective use for this purpose is described.

Premixed bituminous materials, used either for road bases or as surfacings, might perhaps be considered inappropriate for low-cost roads. Some low-cost roads, however, may require strengthening some years after construction because of traffic growth. In such cases premixed bituminous overlays are appropriate. The performance of premixed bituminous materials in temperate climates is well established, but less information is published about the performance of different mix types in hot climates. This Report reviews specifications of premixed bituminous materials for use in hot climates and discusses appropriate construction techniques.

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SUPPLEMENTARY REPORT 284

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by

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BITUMINOUS BASES AND SURFACINGS FOR LOW-COST ROADS IN THE TROPICS

ABSTRACT

Mechanically stable materials for road bases are often not obtainable in developing countries and the technique of soil stabilisation has therefore been developed. In the Middle East, aggregates are often scarce but oil products are readily available. The region has therefore provided some of the earliest examples of bituminous stabilisation, which originally consisted of thin running surfaces over compacted sand. Bituminous stabilisation can also enable local sand to be used for base construction, and various tests and design criteria have been proposed for such applications.

The report describes full-scale experimental trials supported by laboratory research, which have enabled acceptance criteria for bitumen-stabilised sand bases for light/medium traffic to be proposed. Construction methods for bituminous stabilisation are also described.

Details are given of methods of surface dressing, which is important both as an initial running surface on new bases and as a maintenance treatment.

Premixed bituminous materials, both as bases and surfacings, might perhaps be considered as inadmissible for low-cost roads. Such roads, however, usually require progressive improvement because of the traffic growth which accompanies development. There is a growing use of strengthening overlays and the report briefly discusses premixed materials and their application.

1. INTRODUCTION

Much of the accumulated knowledge gained from the construction of roads over the last 150 years relates to the use of mechanically stable roadmaking materials such as crushed rock. These materials are not always available, particularly in the remoter parts of many developing countries, but in recent years the development of the technique of soil stabilisation provides practical alternative roadmaking materials in such situations.

Stabilisation of soil and gravels with cement and hydrated lime is now well-established,[1,2,3] notably in Africa, but in the more arid regions, particularly those with an abundance of non-cohesive superficial materials, bitumen is an appropriate stabilising agent.

The scarcity of aggregates in parts of the Middle East, coupled with the plentiful supply of oil products and the generally arid climate, has encouraged the use of bituminous stabilisation for road construction in the region.

This report discusses appropriate design criteria for sand-bitumen roads carrying light and medium traffic in hot climates.

Bituminous surface dressings are a very appropriate type of surfacing for low-cost surfaced roads. If well-executed they can provide a more satisfactory and cost-effective surfacing than some types of hot-mixed bituminous surfacings. This report discusses the design of surface dressing and briefly describes appropriate construction procedure.

Premixed bituminous overlays are appropriate for strengthening low-cost surface-dressed roads when this is needed because of growth in traffic. The performance of premixed bituminous materials in temperate climates is well established, but less information is published about the design and performance of different mix types in hot climates. This report reviews specifications of premixed bituminous materials for use in hot climates and discusses appropriate construction techniques.

2. CONSTRUCTION METHODS AND THE SELECTION OF BINDERS

Bituminous binders include materials derived from the destructive distillation of coal, naturally-occurring asphalts and petroleum bitumen. The first two are seldom available in developing countries; only petroleum bitumen will be considered in this report.

Bitumen can function in one or more of the following ways, ie as a

(a) lubricant
(b) sealant
(c) adhesive.

These three functions are the basis of all types of bituminous construction, which can be successful only if the type and grade of binder are correctly selected. Selection of the process itself involves a consideration of other features, such as material type or treatment, plant, environment, etc. This is perhaps best illustrated in Table 1, which attempts to summarise several processes, with particular reference to binder viscosity.

3. CONSTRUCTION METHODS FOR BITUMEN-STABILISED BASES

3.1 *Principles of bitumen-bound bases*

Bitumen can be used as a stabilising agent in two ways:

(a) as a waterproofing agent (sealant)
(b) as a binding agent (lubricant/adhesive).

In the waterproofing application, bitumen is mixed with a cohesive soil which has a useful mechanical strength at a given moisture content. The bitumen merely seals the system against moisture changes, thus preserving soil strength. Such applications are rare; more usually bitumen is applied as a binding agent for non-cohesive materials; these can range from a dense continuously-graded crushed rock system (as in asphaltic concrete[4]) to local sand. The former is relatively expensive, the latter relatively cheap; indeed it is becoming increasingly common for road engineers in developing countries to be compelled to use local sand. Comparatively little is known about design criteria for bitumen-stabilised sand, particularly for roads carrying heavy axle loads. The Overseas Unit has cooperated in one full-scale experiment[5] which has given some valuable information, and laboratory research is continuing. (See Sections 3.2.2 and 3.2.3).

3.2 *Experience and research*

It is interesting to consider briefly work done some 40 years ago, mainly in America[6,7,8] and in the Middle East[9], in both of which extensive arid areas occur and through which roads have to be constructed. This work is valuable in that it demonstrates the techniques found to be necessary at a time when construction plant was usually simple and bitumen technology was in its infancy. Basically, little has changed since then, especially in construction methods. The blade grader, for example, is as useful now as before but one is now able to quantify performance criteria to some extent: criteria are discussed later (see Section 3.2.3).

Some early work in the Middle East[9] in the 1930s provided sand-bitumen roads of a very simple construction; sand bitumen produced in simple paddle mixers was spread, and aerated if necessary, by blade graders before compaction with smooth-wheeled rollers. In the absence of mixers, binder was sprayed directly on to the sand and mixed in by grader. Binder contents were evidently sufficiently high to provide adequate cohesion under the abrading action of traffic: this practice would almost certainly be unacceptable today on both economic and engineering grounds. Current practice is to stabilise with sufficient binder to provide adequate shear strength and to seal the surface against traffic abrasion, usually with a surface dressing.

Some valuable precedents were established by the first users of bituminous stabilisation who soon learned that binder viscosity had to be related to the sand temperature and the efficiency of the mixing plant; the importance of cut-back bitumen for this process was thus clear.

3.2.1 The design problem: The study of pavement design may be said to have developed from around the 1940s. Much valuable work was done at this time and has formed the basis of current practice. The California Bearing Ratio method due to Porter[10] is perhaps still the most widely used: the pavement design chart (Fig 1) from the Transport and Road Research Laboratory's Road Note 31[11] relates the strength of subgrade soils to thickness of pavement layers and design life in terms of cumulative standard axles[12]. Minimum soaked CBR values of 80 for crushed stone bases and 100 for cement and lime stabilised material are normally specified. A problem arises, however, in the application of these criteria when constructing bases with bitumen-stabilised soils. Bituminous mixtures behave viscoelastically and are temperature susceptible. In 1954 Nijboer[13] proposed the concept of "stiffness" of a mix, which reflects loading time, acceptable strain (1 per cent max) and maximum temperature experienced in practice. It was shown that this stiffness could be expressed as a ratio of the stability to the flow value (load and strain at failure respectively) measured in the Marshall test[14]. A high ratio may ensure resistance to deformation under traffic but at the expense of a brittle mix. The problem of selecting an appropriate ratio for surfacing materials is considered later (Section 5.1). The application of the concept to bituminous stabilisation is perhaps less important and its relevance probably depends upon the type of traffic using the road and the thickness of the surfacing. The stiffness concept proposed by Nijboer is "rational"; empirical methods, notably the Marshall, Hubbard-Field and the cone penetrometer methods, have also been used for the design of bitumen-stabilised soil bases. A bibliography[15] has been compiled which provides some examples of the use of different design methods and the design criteria adopted.

3.2.2 A full-scale experiment in Africa[5]: Abrasion-resistant sand-bitumen surfaces with relatively high bitumen contents have already been referred to in contrast to the leaner sand-bitumen materials for bases which are more common today. The conflict between abrasion resistance and stability has been recognised for many years. In 1960 the Tropical Section (now Overseas Unit) of the TRRL participated in the construction of experimental sections on a road in Northern Nigeria. These sections were incorporated into a new bitumen-stabilised road, the construction of which has been described elsewhere[16]. It was found that cut-back bitumen with a viscosity of up to approximately 8 x 10^4 centistokes at 60°C (S.125) could be mixed in a simple paddle mixer with the well-graded sand available. The temperature of the sand was 26-28°C and of the binder when added was 120°C (ie at a viscosity of approximately 200 centistokes).

These findings raise the question of whether it is necessary to use sophisticated mixing plant in order to heat sand simply to enable a viscous penetration grade bitumen to be used, even though the superior stability of such mixes on cooling is unquestionable.

The experimental mixes were laid without aeration to remove volatiles and were surface dressed before curing could occur. Materials stabilised with MC2 grade cut-back failed quickly but were the only sections to fail. The remainder have, in general, performed as satisfactorily as those with the hot mix material.

The road has carried mainly light traffic in its 14 years of use and the number of heavy commercial vehicles probably does not exceed 100 per day; this volume of traffic, however, is characteristic of many developing countries.

It is interesting to record that samples of bitumen removed from slabs and taken from several of the experimental sections and from the hot-mixed main contract material after 13 years were all found to have essentially the same viscosity, ie 10-20 pen. A limited number of small samples taken after 18 months showed that the cut-back bitumens had, even at that early stage, cured to the consistency of 80-100 pen.

3.2.3 Research at TRRL on bituminous stabilisation: The principal objectives of the research undertaken by the Overseas Unit were:

1. To evaluate different design methods for bituminous stabilisation.

2. To establish design criteria.

3. To study the behaviour of a variety of sand-bitumen mixtures under different shear conditions.

The first two of these have so far been studied in the full-scale experiment in Nigeria and the results have been reported in full elsewhere[17]. Briefly, sand-bitumen mixtures were prepared using the sand from the Nigeria experiment and three different binders. Mixtures were cured for one year at 45°C and four tests were used to determine stability. Table 2 shows the results of stability tests at 60°C after one year and Table 3 shows some inter-relations of test values for material tested at 45°C.

Of the five design methods originally included in the study, two (Marshall and Hubbard-Field) are well documented[14]. Alexander and Blott[18] proposed the use of the cone penetrometer for sand-bitumen mixtures and it has been frequently used although, as with some other methods, design criteria have been little more than recommendations. It was found that the test did not correlate well with three other methods examined. The deformation wheel-tracking test[19], designed at TRRL and used mainly for studying deformation resistance in surfacings, was the fourth method studied. Tracking rates were found to correlate well with the Marshall and Hubbard-Field methods. The fifth method (CBR) was rejected as inapplicable early in the study.

The following design criteria for sand-bitumen bases for lightly-trafficked roads were deduced from the above study:

Stability, Marshall at 60°C .... 100 kg(min)
Stability, Hubbard-Field at 60°C .... 300 kg(min)

In a recent investigation of the causes of some failures in a road carrying heavy traffic in the Middle East it was found that the type of sand used for the sand-bitumen base varied considerably from place to place along the road and the sand particle texture varied from very rough to very smooth. A limited initial investigation appeared to show a link between failure and bitumen content, and the low residual bitumen contents found (2-4 per cent) were especially noteworthy in relation to the fineness of the sands, most of which passed a 300 μm mesh sieve. The bitumen film thicknesses were thus minimal, and mixes were suspected of being prone to shear failure.

The shear properties of the sands used in this road when stabilised with different percentages of bitumen were studied using a shear box. The effects of binder viscosity and shear rate were also studied. Figure 2 illustrates a typical stress/strain relationship for three sands, showing how the behaviour becomes more plastic as the normal load decreases, ie with increase in depth of construction. Inspection of site failures confirmed Prandtl-type failure,[20] and Fig 3 illustrates the effect of binder viscosity and shear rate on Prandtl bearing capacities for one of the sands.

Calculations based upon the most severe conditions likely to be experienced in a sand-bitumen base showed that the Coulomb equation[21] becomes:

$$\psi = c + 1035 \tan \phi$$

where ψ = shearing stress (kN/m^2)
c = apparent cohesion (kN/m^2)
and ϕ = angle of shearing resistance (degrees).

The results obtained using the shear box are in good agreement with this expression.

Figure 4 shows the relationship between ψ and estimated bitumen film thickness (EBFT) for three sands. The above formula is much simpler to use and to express graphically than the formula derived by Prandtl:

$$\text{Prandtl bearing capacity} = \frac{c}{\tan \phi} \left[\frac{(\sin \phi + 1)}{(\sin \phi - 1)} . e^{\bar{\Lambda} \tan \phi} - 1 \right]$$

where c = apparent cohesion
ϕ = angle of shearing resistance from the Coulomb equation.

It was found that all of the sands possessed optimum ψ values at an EBFT of 0.7 to 0.8 microns, given by

$$\text{EBFT} = \frac{x.10^4}{(100-x)S}$$

where x = bitumen content (% wt)
and S = Specific surface area (cm^2/g).

This recent work has also shown that optimum ψ values for different sands are related to Hveem's centrifuge kerosene equivalent (CKE)[14], the angle of shearing resistance measured by the Angle of Repose method[22], and the Efflux Rate[22] of the dry sand. Results for three sands are plotted in Fig 5.

Whilst this study has been by no means exhaustive, the following conclusions relating to sand-bitumen bases for medium to heavily trafficked roads can be tentatively drawn:

1. (a) For natural dry sand, an angle of shearing resistance of at least 30 degrees and/or CKE of at least 1.5 is required, and

   (b) for the sand-bitumen mix, an EBFT of 0.7 to 0.8 microns with a ψ value of at least 1200 kN/m^2 is required at $25^\circ C$ and rate of strain of 2.22×10^{-2} sec^{-1}.

2. Comparative criteria for the Marshall and Hubbard-Field stabilities are as follows:

   Marshall stability of 300 kg(min) at $60^\circ C$, or

   Hubbard-Field stability of 700 kg(min) at $60^\circ C$, both accompanied by an EBFT of 0.7 to 0.8 microns.

3.3 *The mix-in-place process*

It is worthwhile perhaps to consider carefully what is involved in any mixing process: the requirement may perhaps be expressed in two parts:

1. the components must be brought together
2. an adequate mixing action must be provided.

The first statement may seem obvious but deserves discussion. The stabilisation process involves natural soil as the major component and the stabilising agent less than 10 per cent of the final product. It should therefore be rational to bring the stabilising agent to the natural sand; for example, in cement stabilisation the stabiliser is very often spread on the soil and mixed in by machine in one or more passes. This type of process, mix-in-place, often requires only simple plant, eg trucks, graders and water bowsers, and high output is possible. There are several drawbacks to this process however; in particular, difficulties are often experienced in controlling bitumen content, completeness of mixing and processing depth. Whilst these difficulties are lessened by the use of purpose-built single-pass stabilisation machines, mechanical failure usually results in complete stoppage of work. For this reason simpler multi-pass equipment has much to commend it.

Single-pass machines require the soil to be spread in a windrow such that it can be picked up by the machine as it travels slowly forward; the stabilising binder is added to the soil and mixed within the machine and is discharged from the rear, usually again as a windrow, ready for subsequent spreading and compaction.

An arrangement used on one contract in the Arabian Gulf consisted of a tractor-mounted mixer equipped with a spray bar above the tines inside the mixing hood and supplied with cut-back bitumen by a tanker which preceded it. A metered quantity of bitumen was thus delivered to the soil under the mixing hood but mixing was incomplete during the first pass: subsequent passes of the machine, without the bitumen supply, and assisted by a blade grader were necessary to complete the mixing process. In its simplest form multi-pass work must often be done using only a bitumen distributor and blade grader.

3.4 *The premix process*

Mix-in-place work is only possible where low viscosity binders, ie cut-backs or emulsions, are to be used. If it is necessary to stabilise with penetration grade binders, premix plant is required, although techniques are now available for stabilising with foamed penetration grade bitumen; Mobil Oil (Australia)[23] describe equipment for both mobile and static processes and Bowering[24] discusses the properties and behaviour of foamed bitumen mixtures.

Several points should be made concerning the role of static premix plants for bituminous stabilisation:

(a) Continuous type mixers, which are often capable of high outputs, are well suited to this type of work, ie production using a cold feed of constant gradation; materials are metered by volume. For stabilisation work the process becomes one of soil and binder only in most cases. Production of uniform quality is therefore more feasible than for surfacing materials, which demand close control. Batch-type mixers are essential for surfacing work and can naturally also be used for stabilisation.

(b) Pre-mixed stabilised material can be laid by paver to uniform depth and regularity; shaping by blade grader is thus cut to a minimum.

(c) Modern mixing plants are often constructed as several mobile units, capable of disconnection and re-assembly within a few hours. Such plants can follow the progress of work, thus keeping haul distances to a minimum.

3.5 *Compaction*

The thickness of bitumen coating in soil-bitumen systems is relatively thin, conferring cohesion rather than providing lubrication, and in this respect such systems resemble dense continuously-graded surfacing materials, such as asphaltic concrete, in which the interlocked mineral particles resist compaction. In common with these materials, soil bitumen is compacted most effectively by the kneading action of rubber or pneumatic-tyred rollers.

4. SURFACINGS FOR LOW-COST ROADS

4.1 *The role of surfacings*

Irrespective of its type, a surfacing is basically any treatment which can withstand the abrasive effects of traffic, and many processes will satisfy this definition. The structure of a low-cost road may take several forms:

(a) a compacted and shaped in-situ soil structure;
(b) a cement/lime stabilised base or a mechanically stable base;
(c) a bitumen stabilised base.

Surfacing must be provided in all cases and must moreover be impervious, even in areas of very low rainfall. Base materials are designed to retain sufficient strength in a soaked condition but subgrade/sub-base must be protected. It follows therefore that although pervious open-textured bituminous materials are used for resurfacing on some minor roads, in the UK for example, they must be laid over structures which are known to be adequately sealed by former surface dressings. Where such materials are used as surfacings on new roads, surface dressing is indispensable.

4.2 *Surface treatments*

The term 'surface treatments' is used here to describe processes in which bitumen is applied directly to the surface of a road. Surface treatments commonly used include:

1. Dust-laying processes
2. Priming
3. Surface dressing.

Treatments 1 and 2 are described briefly and surface dressing in rather more detail.

4.2.1 Dust-laying processes: These processes are used to abate the dust nuisance resulting from loose surface material, a feature of many unimproved roads in the tropics. An RRL publication[25] gives detailed information on the subject; low viscosity cut-backs of the MC30 (MCO/MCl) type may be applied at 0.55 - 1.35 l/m^2 (0.1 - 0.25 gal/yd^2) or, less preferably, crude oil, bunker grade fuel oil, etc may be used at heavier application rates. These simple applications are not very durable and, since loose material is being treated, they cannot be considered as equivalent to prime coats. Their effectiveness will be governed mainly by the residual bitumen content of the binder and the application rate. In conclusion, dust-laying must be regarded as a palliative and not a permanent solution to the problem: the latter is obtained by more expensive methods, eg mix-in-place stabilisation of the loose material so as to provide a coherent layer of at least 4-5 cm. The so-called road-mix method of mix-in-place stabilisation is referred to in Section 5.3.

4.2.2 Priming: A prime coat prepares the surface of a new road base for superimposition of a surface dressing or bituminous 'premix' surfacing: a low viscosity cut-back, MC30 (MCO-MCl), is applied at 0.4 - 1.09 l/m^2 (0.08 - 0.20 gal/yd^2) to the brushed and slightly damp surface. It should penetrate to at least 4-5 mm leaving a matt dry surface in 24 hours.

If surface dressing is to follow, binder can be applied directly to the dried prime coat. However, if a premixed surfacing is applied, a tack coat may be necessary to ensure interlayer adhesion, especially if the mix is of a dense type with no large stones to give a mechanical 'key' to the base. The engineer must judge the need for a tack coat in each case; a useful guide on prime and tack coats for use in Africa has been published[26].

4.3 *Surface dressing*

Surface dressing, also known as a 'spray and chip' process, is a surfacing treatment of the highest importance not only in developing countries but also in many industrialised countries of Europe. It can be used as an economical first surfacing, either as an improvement of an existing road or as part of the initial construction of a new road. Further surface dressings can be applied as a maintenance process: the life of all forms of premixed bituminous surfacing is extended by the periodic use of surface dressing as a maintenance treatment. Some references[27,28,29,30] are given to the extensive literature on surface dressing. A surface dressing seals the road structure against surface water and presents a rugous stone layer to vehicle tyres. The base is thus protected against attrition but the single layer of stone chippings applied cannot restore riding quality to an irregular pavement or contribute significantly to pavement strength.

4.3.1 Surface dressing design: Although the most important feature of surface dressing is the provision of a continuous impervious film of binder, the success in the design of the dressing begins with selection of the appropriate sizes for the stone chippings, which protect the film from damage by vehicle tyres. Selection depends upon the weight and nature of traffic and penetrability (softness) of the existing surface. That choice having been made, an appropriate thickness of sprayed binder can be selected.

The following stages are necessary:

Select a nominal chipping size for the job; the most frequently used sizes are 14 mm (approx ½ inch) and 10 mm (approx ⅜ inch). The former size is preferable for roads carrying large numbers of heavy commercial vehicles and the latter for lightly-trafficked roads often used by fast-moving vehicles. Extreme cases are soft bituminous surfaces carrying very heavy vehicles (20 mm) and very hard, eg concrete, surfaces (6 mm); these cases will seldom be encountered in developing countries but are included for completeness. Table 4 shows the recommended nominal size of chippings in relation to hardness of surface and traffic loads. Table 5 gives the rates of spread for four nominal sizes of chippings when using cut-back binder. Road Note 39[27], in which this Table appears, stresses the need to consider the shape and specific gravity of chippings in addition to size when selecting the rate of spread.

Jackson[30] discusses the effect of the shape of chippings and provides a design method based upon the Average Least Dimension of chippings. His procedure may be summarised as follows:

(a) Measure the least dimension of approximately 200 chippings to determine the Average Least Dimension (ALD) of the stone. Chippings of a given nominal size can have different ALDs. These differences affect the application rates of chippings and binder. Refer to Figure 6; take the intercept of ALD and line AB and read off appropriate rate of spread from upper scales.

(b) Select from Table 6 an appropriate constant from each of the four sets of conditions listed. Sum the four constants to obtain an overall factor and refer to Figure 6, take intercept of ALD and overall factor line determined above and read off binder application rate from lower scales.

4.3.2 Choice of stone: Aggregate should be clean, dust-free and should comply with requirements of the type given in BS 63[31]. Chippings should be roughly cubical; flaky and elongated stones tend to be broken under the roller or to be picked out by traffic. Rounded aggregates require more binder than angular ones and offer less skid resistance. Polished stone value (PSV)[32] is the main factor which affects the skid resistance of surface dressings and recommended values for different site conditions in the UK have been published[33] (see Table 7).

Aggregates of high crushing value sometimes show a tendency to polish. Low strength aggregates may abrade and develop surfaces of poor skid resistance;[34] such aggregates are particularly susceptible to crushing when rolled with a steel-wheeled roller, and pneumatic or rubber-tyred rollers are preferable. Occasionally coarse sand is the only cover aggregate available and can be used for seals under light traffic. In other situations, such unconventional aggregates as lightly broken cockle shell or coral have been successfully used.

Some authorities specify different stone sizes for the first and second layers of double surface dressings, eg 14 mm for the first layer and 10 mm for the second; other users occasionally reverse the order.

Experience at TRRL has shown that there appears to be no advantage in changing the size of stone for the second layer. When applying a double surface dressing to concrete, however, a small size, eg 6 mm, would be used for the first layer followed by a 10 mm chipping for the second layer.

The sprayed binder film rapidly wets the surfaces of clean chippings. Dusty chippings are less easily wetted and adhesion will be delayed. Traffic then 'whips off' the chippings: disastrous failure is especially likely to occur if rain falls within two or three hours of chipping. Where water to wash the chippings clean is in short supply, an alternative often used is to pre-treat the chippings with a very small amount (0.5 per cent by weight) of bitumen: these are referred to as 'lightly coated' in order to distinguish them from the 'precoated' chippings applied to rolled asphalt (see Section 5.1). Chippings must be capable of being spread by standard gritting machinery and must therefore not be tacky and liable to agglomerate. In the UK a light coating of bitumen or tar is applied to chippings in most surface dressing jobs, and almost always when treating heavily-trafficked roads which must be opened to vehicles immediately upon completion of the process. Coating temperatures at the mixing plant are somewhat higher than normal in order to produce a lacquer on the chippings; this ensures rapid adhesion to the film of sprayed binder. If coating plant is not available, a light spray of diesel oil, kerosene or very fluid cut-back can be used. The above treatments are not recommended when surface dressing with bitumen emulsion.

The above reference to pre-treating chippings is included for completeness, although it is appreciated that such treatments may not be feasible within the context of low-cost roads and are, indeed, seldom necessary provided that attention is paid to correct choice of binder (see below), aggregate size and construction procedure.

4.3.3 Choice of binder: Selection of binder is often dictated by availability; nonetheless, an understanding of binder behaviour can prevent disasters. The simple rule for surface dressing binders is that they should have a viscosity of between 10^4 and 5×10^5 centistokes at the prevailing road temperature. At higher viscosities, stone will not be wetted by the binder and will be lost by whip-off: at lower viscosities wetting will occur but the binder will be too fluid to hold the stone.

Figure 7 shows the viscosity/road temperature relationship for a wide range of binders. It will be clear that for most conditions in the tropics suitable surface dressing binders will be MC3000 (MC4/MC5) or soft penetration grades up to 80/100 grade. The use of a more viscous bitumen than 80/100 is not recommended and should not be necessary. Bitumen of 60/70 penetration grade is generally available in the Arabian Gulf area and can be cut-back with diesel at a rate of 5 gal/100 gal of 60/70 pen to give a bitumen in the range 300-400 pen suitable for surface dressing at road temperatures of 40-65°C approximately. Occasionally chippings have to be spread manually instead of by mechanical gritters; in such cases it may be advisable to use a slightly less viscous binder than that theoretically required.

The role of bitumen emulsion in surface dressing should be discussed at this stage. The usefulness of the commonest and cheapest form of bitumen emulsion - anionic emulsion - is limited by several features:

1. Poor adhesion to dry dusty surfaces.

2. The effective bitumen content (seldom exceeding 55 per cent).

3. Suitable source of supply, transportation and storage.

Conditions in the Middle East are predominantly dry and dusty and do not therefore favour the use of anionic emulsions, which are better suited to cool and damp conditions. For this reason special cationic emulsions of higher viscosity and containing 70-75 per cent bitumen have been developed in recent years, for example, for surface dressing in the early spring months in the UK. It is stressed, however, that these emulsions are sprayed at approximately 80°C; 65 per cent cationic emulsion as used in South Africa[35] requires heating to 70°C before spraying and the advantage of use in unheated equipment is lost. The low viscosity of some emulsions is a disadvantage in surface dressing in that they tend to drain from the crown of the road before break occurs: cover aggregate is therefore poorly held at the crown and is lost, whilst excess binder accumulates at the edges and leads to bleeding.

Apart from considerations of bitumen content, the grade of base bitumen present in an emulsion is important and may need to be varied according to season and traffic conditions[35]. Finally, coagulation can occur when some emulsions are transported or stored in unsuitable conditions.

It is tempting to assume that when hot binder is not available, bitumen emulsion applied at ambient temperature is a simple alternative. Indeed, emulsions are often used for successful surface dressings - but the Engineer should be aware of the problems cited above that can arise. Careful attention to technique of application is needed.

4.3.4 Construction procedure: Construction methods for surface dressing are adequately described elsewhere[27,30]; attention to detail and good planning will ensure success. Excellent equipment is now available for surface dressing. Recent developments in the UK have included the following:

1. Constant-rate-of-spread distributor (binder metering pump coupled to distributor transmission).

2. Extending spray bar (spray width adjustable whilst spraying: for use with 1 above).

3. Forward-control, self-propelled metering gritter (tows chipping lorry; operator has excellent view of work).

The process selected should be suitable for the function expected of it; it is appreciated that cost considerations often affect the choice. Generally a double surface dressing is preferred on new bases; single dressings are sometimes used however, particularly on lightly-trafficked roads and as temporary seals. Single dressings are used for road maintenance and are particularly valuable for treating badly polished slippery surfaces often found at road junctions, traffic lights, etc, in cities.

The use of adhesion agents in surface dressing (and bituminous premix) overseas is sometimes advised. These are correctly used to prevent traffic damaging a new surface dressing when rain may be expected to fall within two or three hours of construction, ie before chippings are thoroughly wetted by the binder and orientated into a matrix by traffic; fast vehicles are particularly damaging in these cases. When needed, these agents are usually blended with the binder in small amounts, often only 1-2 per cent by weight, but are rapidly decomposed by heat and the treated binder must be used within 1-2 hours of blending. Some agents in solution can be sprayed on to the aggregate before chipping commences or even directly on to the sprayed binder film. Normally, however, provided that clean chippings are used with the appropriate grade of bitumen, adhesion agents are not required. When it is difficult to obtain dust-free chippings, the light-coating treatment for chippings described earlier (section 4.3.2) may be an economical alternative to the use of adhesion agents.

4.3.5 Surface dressing as a maintenance treatment: Surface dressing is undoubtedly the cheapest and most widely used process for the maintenance of road surfacings generally. A new road surfaced with a dense and expensive wearing course will require maintenance, sometimes within the first three years. The effects of traffic, climate and constituent materials, often combined with those of errors in mix production, can produce several conditions:

Condition	Causes	Result
(a) Lean 'hungry' surface	Bitumen content too low Poor mix design Poor process control Binder hardened and embrittled	Surface frets; stone lost, ravelling may occur (damage to windscreens)
(b) Fatting up or bleeding	Binder content too high Poor mix design Poor process control	Possibility of excess binder on surface; surface slippery. Pushing and/or rutting Skidding accidents
(c) Surface hard but polished	Exposed hard stone polishes under traffic	Skidding accidents, especially when wet

These conditions occur regularly and can usually be treated by surface dressing, provided that local depressions, pot-holes, etc are rectified beforehand; it is customary in the UK to burn off any excess binder from bleeding areas using specialised equipment. Surface dressing is a valuable maintenance treatment providing a waterproof seal, additional cover aggregate and an anti-skid surface at a cost which is 20-30 per cent of that of the thinnest practicable premix overlay.

Rolled asphalt, which is dealt with in Section 5.1, is a dense bituminous premix used in the UK for the surfacing of all main roads and has a life of 20-25 years. The layer of pre-coated chippings (20 mm) applied as an anti-skid measure during laying may remain effective for some 10-15 years (more or less depending on numbers of heavy vehicles). Thereafter surface dressing is done at 4-5 year intervals. Traffic on motorways can be exceptionally heavy and surface dressing is then required more frequently.

4.4 *Slurry seals*

These materials may be considered as intermediate between surface treatments and premixed materials with respect to cost and performance. They are basically mixtures of fine aggregate, water, bitumen emulsion and occasionally cement. Where new seals have to be opened to traffic soon after laying, chemicals are added to break the emulsion within a controlled period. Some UK treatments can be trafficked within 2-3 minutes of laying; a typical composition would be:

combined aggregate (5 mm down)	70-80% weight
water	7-10% weight
emulsion	13-20% weight

Anionic or cationic emulsions may be used. Anionic slurries may be premixed in a static mixing plant, but, because emulsions in cationic slurries break relatively quickly, these slurries have to be prepared in a purpose-built mixing and laying machine.

Slurry seals are of fluid consistency when applied and can thus penetrate and seal cracks and surface voids. The resulting layer, some 3-4 mm thick, improves the riding quality of the road to some extent depending upon the laying technique. This can range from simple squeegees to modern mixer-spreader units; costs are higher than for surface dressing but may be justified for old badly-cracked or lean bituminous surfacings. In South Africa slurry seals are sometimes applied to new surface dressing, thus furnishing a superior type of seal, often referred to as 'cape seal'.

They are particularly useful for re-sealing aerodrome runways[36] and standard reference works[37] are available. The runways of two international airports in the Arabian Gulf area have been successfully re-sealed using the slurry seal process. One of these was badly cracked and abrasion loss was occurring; in the touch-down areas particularly, disintegration was imminent due to embrittlement of the binder. A double seal, 2 x 3 mm, was applied at these areas and a single seal over the major portion of the runway. The treatment has been entirely successful at both airports.

5. PREMIXED BITUMINOUS SURFACINGS AND THE LOW-COST ROAD

In the context of low-cost roads, premixed bituminous surfacings would appear initially to be both unnecessary and economically unjustified. The following points, however, should be considered:

(a) New roads are invariably found to generate traffic; the estimated daily usage is often exceeded early in the life of a road.

(b) The low-cost road of today can become the important route of tomorrow. Access to what were formerly inaccessible areas encourages development. Howe[38] has concluded from available evidence that most forecasts of rural traffic in developing countries are subject to considerable error: a ± 50 per cent confidence interval is likely.

The design history of many low-cost roads in developing countries, notably those in Africa, may be summarised simply as follows:

(i) Initial construction	Subgrade	CBR = 25 (min)
	(100 mm (min) sub-base, CBR = 25 (min), where subgrade has CBR less than 25 at equilibrium moisture content).	
	150 mm Base a)	Stabilised, soaked CBR = 100 (min)*
	or b)	Mechanically stable, soaked CBR = 80 (min).
	Double surface dressing	
	(*Does not apply to bitumen-stabilised sand)	
(ii) Strengthening overlay	50 mm (min) bituminous premix.	

It is imperative that the benefits expected at Stage (ii) should be realised in full, particularly in view of the high cost of bituminous materials. Bituminous overlays often fall short of their objectives for various reasons, among which are:

(a) inappropriate premix type;
(b) inadequate materials and manufacturing equipment;
(c) inadequate control of manufacture.

The characteristics of different mix types and their application are discussed briefly.

5.1 *Bituminous premix types*

Bituminous mixes may be considered as being of two main types, the performance of which depends upon:

(i) the mechanical interlock of aggregate
(ii) the stiffness of a bituminous mortar.

Type (i) comprises those materials known generally as macadams, eg as described in BS 4987[39]; bitumen of very high viscosity is not required in these mixes since stability is obtained by the interlock of particles which must, however, be lubricated during the compaction process. The well-known 'asphaltic concrete'[4] is a very dense continuously-graded macadam. The Marshall mix design method is generally used to determine the 'optimum' binder content, which must reflect the condition of optimum packing of aggregate (and therefore optimum lubrication) together with optimum cohesion. This is the condition for maximum stability which is often given attention at the expense of flexibility. Nijboer[13] introduced the idea of mix 'stiffness' and it was subsequently concluded that an approximate value could be calculated as follows:

$$\text{Stiffness} = \frac{\text{Marshall stability (lb)}}{\text{Marshall flow (0.01 in)}} = 1.2 \times \text{tyre pressure (lb/in}^2\text{)}$$

Certain assumptions and approximations were made in arriving at this simple relationship; nonetheless, it appears to have been supported reasonably well by the results of field and laboratory tests. Experience at TRRL is that mixes produced in the developing countries often have an unnecessarily high stiffness. Marshall design criteria for road surfacings in the tropics have been calculated for three types of traffic on the basis of assumed tyre pressures, permissible flow values and the stiffness calculated as shown above. The results are given in Table 8.

Type (ii) mixes are bituminous mortars, ie sand is coated with a very viscous bitumen which has been further stiffened by the addition of filler. Stone is usually added as an extender and enhances stability. In the UK these stone-filled mortars are known as rolled asphalts, and are described in BS 594:1973[40]. The gradings of stone and sand are specified separately and a discontinuity appears in the overall grading: rolled asphalts are therefore often referred to as 'gap-graded' mixtures. Compositions have evolved from experience and the resulting recipes consistently define materials with lives of 20-25 years, requiring only routine re-texturing by surface dressing. Initially, rolled asphalts containing less than approximately 45 per cent stone are given, as an anti-skid measure, an application of coated chippings during laying.

5.2 *Experience and research*

Macadam and rolled asphalt compositions for use in the UK have evolved over many years of experience without the need for mix design procedures. In contrast, asphaltic concrete has come into general use in the developing countries, especially in the tropics: this is understandable because of high road temperatures. It is usually found that asphaltic concrete correctly designed, mixed and laid performs well under fairly continuous traffic, the tyres of which tend to keep the surface 'closed'. Troubles are common when such surfacings are very lightly trafficked, particularly by fast moving cars. Aggregate particles in the surface tend to be picked out instead of being re-embedded into the matrix, for which slow, high-pressure tyres are required. Picking can develop rapidly into severe ravelling: this can and does occur very easily with materials made to specifications which result in low 'optimum' bitumen contents. Table 9 contains two recommended specifications for asphaltic concrete. The aggregate particles in asphaltic concrete are very thinly coated: mixes tend to be brittle and to develop cracks which are not self-healing.

In recent years the Overseas Unit, TRRL, has been examining the relative performances of different premix types in tropical and sub-tropical conditions. At one experimental site in the Arabian Gulf the performance of asphaltic concrete, surface dressing, open and dense macadams and rolled asphalts is being compared. Whilst there is no noticeable deterioration of any of the sections after three years of use, it is encouraging to note that the rolled asphalt sections show no signs of rutting. A second and more extensive group of experimental sections constructed in Turkey[41] is devoted almost entirely to rolled asphalt surfacings but is relatively new: further opportunities for trials are being sought, the objective being to establish suitable surfacing specifications for given environments. Gap-graded compositions are already in use in South Africa and Table 10 shows a specification used in Natal[42].

Where doubt exists as to a suitable surfacing specification, a 'recipe' such as the Group 3 (14 mm) wearing course shown in Table 9 can be adopted: if necessary this would be sealed with a surface dressing. For lightly-trafficked roads it will be advisable to use binder contents at the higher end of the appropriate range. Compared with asphaltic concrete such a mix will have higher voids and will be permeable; however, the aggregate will be well-coated and the risk of bleeding (resulting from poor production control) will be lessened. The risk of picking and abrasion will be small and the mix will have greater flexibility than asphaltic concrete, cracking being therefore less likely. Table 9 includes three further specifications taken from BS4987[39].

5.3 *Construction techniques*

Excellent construction equipment is available for all bituminous road processes. Recent developments in surface dressing equipment were mentioned earlier (Section 4.3.4); this equipment is relatively cheap compared with sophisticated premix plant.

Bitumen distributors can be used for work other than surface dressing and priming. Where expensive mixing plant is not available it is often possible to manufacture premix by the so-called 'road mix'[43] process:

1. Aggregates are windrowed on a suitable mixing site; this is often a new base, old road or a levelled piece of ground which has been sealed with a bitumen spray.

2. The required quantity of cut-back bitumen is sprayed by a distributor in several applications and a blade grader mixes the material between applications.

3. The mixed material is then spread or, if necessary, aerated for some time to remove volatiles before spreading.

A range of gradations can be mixed by this technique which is limited only by the stiffness of the resulting mix; for this reason the cut-back grade will be determined by prevailing aggregate temperatures. The process is used extensively in bituminous stabilisation for bases and will doubtless be applicable to remote areas in the developing world. Control of mix proportions in this process is poor. Nonetheless, some examples of effective application have been seen in the Arabian Gulf area.

Available premix plant varies in complexity from simple paddle mixers producing approximately 10 tph to fully automatic asphalt plants producing 250 tph. Simple mixers have no aggregate drying unit and are restricted to mixing at ambient temperatures; thus bitumen-stabilised soils can be produced and occasionally coated materials, for which a cut-back bitumen or slow-breaking (stable) emulsion must be used. Aggregates must be pre-wetted when mixing with emulsion, which must be particularly stable when large amounts of fine material are present.

The production of well-controlled premix requires appropriate mixing plant. For high-grade surfacings, particularly those like asphaltic concrete for which binder content control is so critical, only a weigh-batch type plant is permissible. Continuous mixers are susceptible to variations in hot bin level and serious departures from the design grading and bitumen content may occur with these plants, which are better employed for preparing single-size aggregate mixtures or for soil stabilisation. Weigh-batch plants normally have four hot aggregate bins and a filler bin; all fractions are pre-weighed before discharge to the pugmill. Binder proportioning is almost invariably by weigh-batching, which has been found to be more accurate than volumetric devices.

In the UK it is customary to produce macadams in batch-heater type mixers; stone fractions are pre-weighed in the cool state and then combined before loading to the batch-heater. This system is much simpler than that of the more familiar asphalt plant and is well suited to macadams and their lower drying/heating demand. Dense mixtures such as rolled asphalt and asphaltic concrete require much higher heat inputs for drying and involve higher temperatures since the binders used are more viscous than in macadams. The continuous dryers in asphalt plants are better suited to these requirements and, although macadams can be produced effectively with such plants, it is not operationally feasible to produce dense mixtures using batch-heater plants.

5.4 *Asphalt plant operation*

Several points can be made concerning asphalt mixing and paving plant:

1. Where cold feeders at the mixing plant are not charged with several screened materials of different sizes, the gradations of the materials in the hot bins must be checked frequently. Too often an all-in material is cold fed; the contents of the hot bins will then depend entirely upon variations in the stockpile. Materials such as asphaltic concrete cannot be produced under these conditions.

2. Plant output must be adequate for paver laying capacity. The latter usually exceeds production, with the result that the paver stops and restarts frequently, leaving a series of irregularities in the carpet; the problem can be aggravated when insufficient trucks are used.

3. Mix temperatures must be checked frequently; it is not unknown for producers to keep temperatures high in order to speed up compaction, thus increasing output. Appropriate binder temperatures are given in Table 11.

4. The paver must be well maintained, particularly the hydraulic system. Trucks must not be permitted to reverse into direct contact with the paver.

5. The laying gang should not be allowed to back-blind the spread material; this is commonly done for little or no reason and can affect the riding quality. Hand rakes are frequently used to remove excess material at the longitudinal joint: excessive raking invariably segregates coarse stone, leaving open-textured areas.

6. Roller operators can, and will, ruin any laying operation if inexperienced or badly controlled. Correct overlapping of rolled passes by a half width, staggering of stop points, cleanliness of rolls (or tyres), efficiency of cleaning mats and water spray bars are particular points requiring supervision.

There is adequate published work on the operation and maintenance of bituminous construction plant[4,44,45,46,47].

6. ACKNOWLEDGEMENTS

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TABLE 1

Some features of different bituminous processes and materials

Process/Material	Use	Binder function	Binder viscosity (as constructed)	Aggregate system
Priming	binds surface of new base in preparation for surfacing	sealant	low	nil
Tack coating	provides bond between existing surface and bituminous premix overlay	adhesive	high	nil
Surface dressing	re-sealing re-texturing	sealant and adhesive	low/medium	single-size chippings
Slurry sealing	sealing open/'hungry'/cracked bituminous surfacings	sealant/adhesive	low	dense, very fine
Macadams (includes asphaltic concrete)	bases, surfacings	lubricant/adhesive	medium/high	angular, interlocking (very open - very dense)
Mortar type mixes (includes rolled asphalt)	bases, surfacings	adhesive/sealant	V. high	very dense; may include stone

TABLE 2

Properties of sand-bitumen mixes after 1 year (+) storage at 45°C
Stability tests at 60°C (all compacted densities, CDM, in Mg/m^3)
(Sand: as for construction of experimental sections, Maiduguri-Bama road)

Binder	% wt	Cone stability				Deformation wheel tracking test		Hubbard-Field		Marshall			Properties of recovered binder		
		S	m	y	CDM	Rate of deformation (mm/min)	CDM	Stability (kg)	CDM	Stability (kg)	Flow (mm)	CDM	Penetration at 25°C	Viscosity (absolute) (poises x 10^4) at 45°C	Viscosity (absolute) (poises x 10^4) at 60°C
MC2	3	2.7	1.8	0.9	1.91	0.036	1.91	293	1.93	206	2.0	1.87	92	5.89	0.66
	4	2.2	1.3	0.9	1.92	0.098	1.92	304	1.93	170	1.8	1.89	88	16.2	0.12
S.125	3	2.7	1.8	0.9	1.91	0.036	1.91	413	1.92	337	2.0	1.89	58	13.6	2.2
	4	2.4	1.5	0.9	1.92	0.038	1.92	468	1.93	327	2.0	1.91	65	18.5	2.2
80/100 pen	3	1.7	0.9	0.8	1.90	0.094	1.90	343	1.91	256	2.0	1.88	44	16.7	4.0
	4	1.6	0.8	0.8	1.92	0.041	1.92	333	1.93	219	2.0	1.91	42	16.0	1.8

TABLE 3

Hubbard-Field/Marshall stability ratios and cone stability/equivalent tyre pressure (imperial) relationships; uncured and cured material; tested at 45°C

(Sand: as for construction of experimental sections, Maiduguri-Bama road)

Binder	Uncured						Cured 1 year (+) at 45°C					
	Binder content (% wt)	Hubbard-Field (kg)	Marshall (kg)	Hubbard-Field/ Marshall ratio	Cone stability (S) (kg/cm^2)	Equivalent tyre pressure (lb/in^2)	Binder content (% wt)	Hubbard-Field (kg)	Marshall (kg)	Hubbard-Field/ Marshall ratio	Cone stability (S) (kg/cm^2)	Equivalent tyre pressure (lb/in^2)
MC2	3	SPECIMENS UNSTABLE			2.9	41	3	671	382	1.76	11.0	156
	4				3.0	42	4	578	421	1.37	8.9	126
S125	3	198	79	2.51	3.1	44	3	587	473	1.24	9.6	136
	4	197	44	4.48	3.4	48	4	637	425	1.49	9.0	128
80/100 pen	3	420	232	1.81	2.7	38	3	507	384	1.32	7.9	112
	4	517	192	2.69	3.4	48	4	586	391	1.50	6.0	85

TABLE 4

Recommended nominal size of chippings (millimetres)

Type of surface	Lane Traffic Category — Approximate number of commercial vehicles currently carried per day in the lane under consideration				
	(1) Over 2000	(2) 1000-2000	(3) 200-1000	(4) 20-200	(5) Less than 20
Very hard	(10)	10	6	6	6
Hard	14	14	10	6	6
Normal	20+	14	14	10	6
Soft	*	20+	14	14	10
Very soft	*	*	20+	14	10

Note:

The size of chipping specified is related to the mid-points of lane traffic category ranges 2-5: lighter traffic conditions may make the next smaller size of stone more appropriate.

+At the discretion of the Engineer, 20mm chippings may be used for remedial treatment where traffic speeds are low. Very particular care should be taken when using 20mm chippings to ensure that no loose chippings remain on the surface when the road is opened to unrestricted traffic as there is a high risk of windscreen breakage.

*Unsuitable for surface dressing.

TABLE 5

Rate of spread when using cut-back bitumen

Type of Surface	Lane Traffic Category (See Table 4) 1		2		3		4		5	
	Chipping Size (mm)	Binder Rate (litre/m^2)	Chipping Size (mm)	Binder Rate (litre/m^2)	Chipping Size (mm)	Binder Rate (litre/m^2)	Chipping Size (mm)	Binder Rate (litre/m^2)	Chipping Size (mm)	Binder Rate (litre/m^2)
Very hard	Not recommended		10	1.0*	6	1.0	6	1.1	6	1.2
Hard	Not recommended		14	1.1$^+$	10	1.0	6	1.0	6	1.0
Normal	Not recommended		14	1.0$^+$	14	1.0	10	1.0	6	1.0
Soft	Conditions not suitable for surface dressing		20≠	-	14	0.9	14	1.0	10	1.0
Very soft	Conditions not suitable for surface dressing				20≠	0.9	14	0.9	10	0.8

* Rubberised cut-back bitumen only is recommended.

+ Evidence is being sought for successful use of bitumen in these categories.

≠ At the discretion of the Engineer, 20mm chippings may be used for remedial treatment where traffic speeds are low.

TABLE 6

Traffic	Veh/day	Constant	Type of chippings	Constant
Very light	0-100	+3	Round/dusty	+2
Light	100-500	+1	Cubical	0
Medium	500-1000	0	Flaky	-2
Medium Heavy	1000-3000	-1	Pre-coated	-2
Heavy	3000-6000	-3		
Very heavy	6000+	-5		

Existing surface	Constant	Climatic conditions	Constant
Untreated/primed base	+6	Northern Europe (wet and cold)	+2
Very lean bituminous	+4	Tropical (wet and hot)	+1
Lean bituminous	0	Temperate	0
Average bituminous	-1	Semi-arid (dry and hot)	-1
Very rich bituminous	-3	Arid (very dry and very hot)	-2

TABLE 7

PSV of aggregate necessary to achieve the required skidding resistance in bituminous surfacings under different traffic conditions

Required mean summer SFC at 50 km/h	PSV of aggregate necessary					
	Traffic in commercial vehicles per lane per day					
	250 or under	1000	1750	2500	3250	4000
0.30	30	35	40	45	50	55
0.35	35	40	45	50	55	60
0.40	40	45	50	55	60	65
0.45	45	50	55	60	65	70
0.50	50	55	60	65	70	75
0.55	55	60	65	70	75	
0.60	60	65	70	75		
0.65	65	70	75			
0.70	70	75				
0.75	75					
Aggregate abrasion value	not greater than 12			not greater than 10		

SFC = sideway force coefficient

(hatched cells) SFC values in these traffic conditions are sometimes achievable with aggregates of extreme hardness and very high resistance to abrasion, such as certain grades of calcined bauxite

TABLE 8

Suggested Marshall design criteria for road surfacings in the tropics

Traffic level	Tyre Pressure (P) range (lb/in^2)	Stiffness, S/F* = 1.2P	Range of flow values (in x 10^{-2})	Calculated Stability range (lb)	Suggested range of Marshall stability and flow values				S/F Range		
					lb	inx10^{-2}	kg	mm	$\frac{lb^{\neq}}{inx10^{-2}}$	$\frac{kg^{\neq}}{mm}$	$\frac{kN}{mm}$
Light	40-50	48-60	8-20	380-1200	700-1200	12-20	315-545	3.0-5.1	35-100	60-180	0.6-1.8
Medium	60-75	72-90	8-18	580-1620	1000-1600	11-18	455-725	2.8-4.6	55-145	100-250	1.0-2.5
Heavy	80-100	96-120	8-16	770-1920	1200-1900	10-16	545-860	2.5-4.1	75-190	135-340	1.3-3.3

* $S/F = \frac{\text{Stability (lb)}}{\text{Flow (in x } 10^{-2})}$ obtained in Marshall test

≠ to nearest 5

TABLE 9

Typical specifications for bituminous premix

Authority	Shell International Petroleum Co		British Standard 4987			
Mix type	Asphaltic concrete Binder course	Asphaltic concrete Wearing course	Group 1 Road base (40 mm nominal)	Group 2 Dense basecourse (28 mm nominal)	Group 3 Dense wearing course (14 mm nominal)	Group 4 Coarse cold asphalt (10 mm nominal)
Aggregate grading (% wt passing) (total aggregate)						
50 mm			100			
37.5 mm			95 - 100	100		
28 mm	100		70 - 94	90 - 100		
20 mm	80 - 100	100		71 - 95	100	
14 mm	60 - 80	80 - 100	56 - 76	58 - 82	95 - 100	100
10 mm	-	-			70 - 90	95 - 100
6.3 mm	-	-	44 - 60	44 - 60	45 - 65	70 - 90
5 mm	35 - 56	54 - 72				
3.35mm	-	-	32 - 46	32 - 46	30 - 45	
2.36mm	28 - 44	42 - 58				40 - 60
1.18mm	20 - 34	34 - 48			15 - 30	
600 µm	15 - 27	26 - 38				15 - 30
425 µm	-	-				
300 µm	10 - 20	18 - 28	7 - 21	7 - 21		
150 µm	5 - 13	12 - 20				5 - 15
75 µm	2 - 6	6 - 12	2 - 8	2 - 8	3 - 7	3 - 10
Bitumen Content (% wt total mix) Crushed rock	4.8 - 6.1	5.7 - 7.0	2.9 - 4.1	4.1 - 5.3	4.4 - 5.4 (A) 4.6 - 5.6 (B)	4.9 - 5.9 (A) 5.1 - 6.1 (B)
Limestone					4.1 - 5.1 (A) 4.4 - 5.4 (B)	4.7 - 5.7 (A) 4.9 - 5.9 (B)
						(A)>300 cvpd) in one (B)<300 cvpd) direction

TABLE 10

Gap-graded overlay specification, Natal, South Africa[42]

BS sieve size (per cent passing)		Coarse aggregate	Fine aggregate
(1 in)	26.5 mm	100	
(¾ in)	19 mm	90 - 100	
(⅜ in)	9.5 mm	60 - 80	
(3/16 in)	4.75 mm	25 - 45	
(No 7)	2.36 mm	15 - 30	100
(No 25)	600 μm	5 - 15	95 - 100
(No 52)	300 μm	-	70 - 80
(No 72)	200 μm	-	45 - 65
(No 100)	150 μm	-	25 - 45
(No 200)	75 μm	0 - 5	10 - 20

Mix composition Coarse aggregate (ret 7 mesh) Fine aggregate (7-200 mesh) Filler (pass 200 mesh) Bitumen (60/70 pen)	 47 ± 5% wt 40 ± 5% wt 7.5 ± 2% wt 5.5 ± 0.3% wt
Filler/bitumen ratio	between 1 and 2*
Marshall stability (min)	340 kg (750 lb)
Marshall flow value	2 - 4.5 mm ($8-18 \times 10^{-2}$ in)
Voids in mix	4 - 10% vol
Suitable for compacted course thicknesses of	30 to 65 mm (1¼ to 2½ in)
Sand equivalent value of combined aggregates (AASHO T.176 - 65)	>45
Aggregate crushing value (BS 812:1967)	<30 per cent

*in the authors' view a filler/bitumen ratio of between 1 and 1.5 is likely to be the optimum ratio in most cases.

TABLE 11

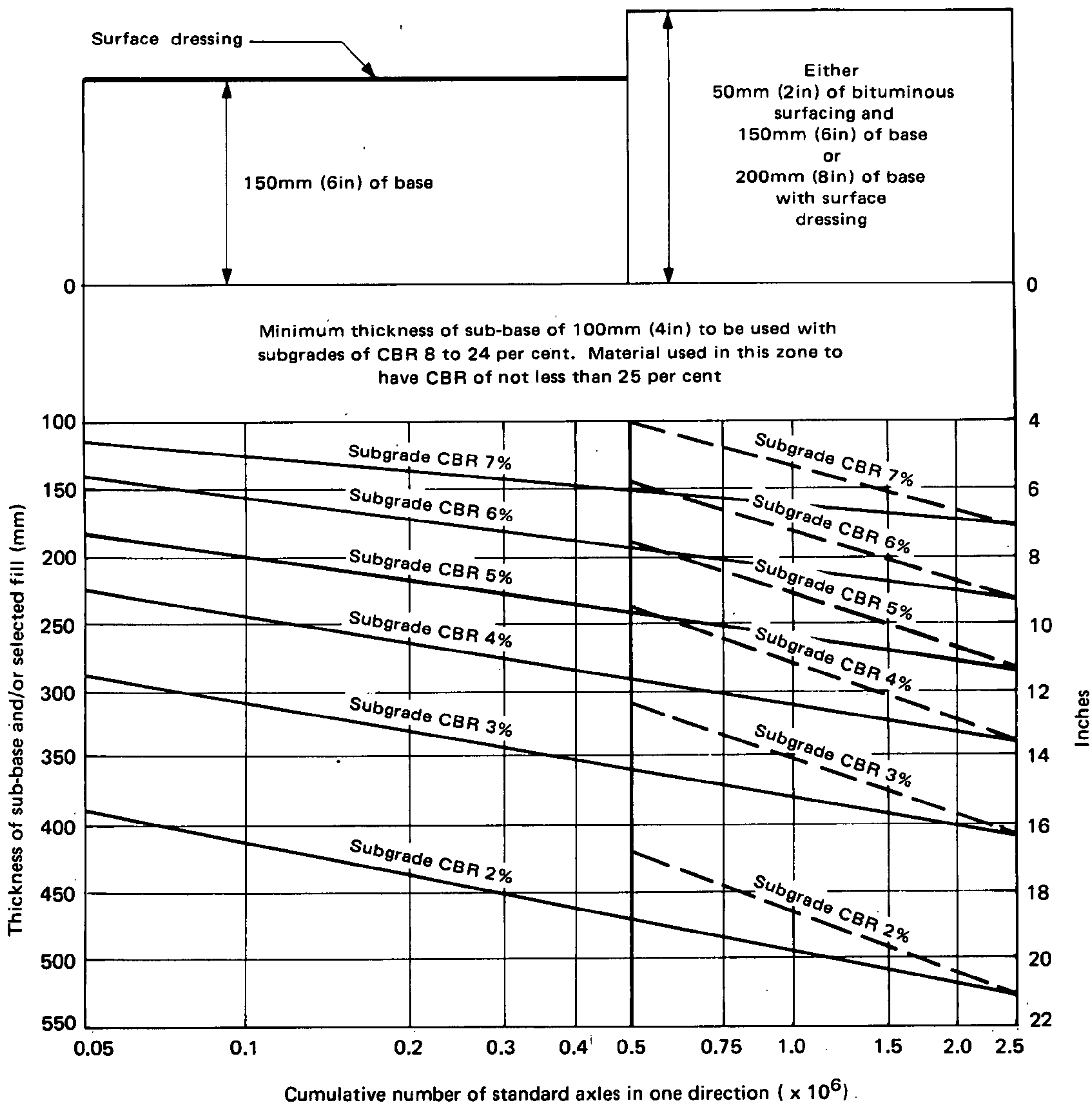
Application temperatures for bitumens and cutbacks

GRADE	Spraying				Mixing	
	Atomising Jets		Slot Jets			
	°C	°F	°C	°F	°C	°F
Cutback grades						
MC/RC0	50- 60	125-145	35- 45	100-120	-	-
MC/RC1	70- 85	165-190	60- 70	140-160	-	-
MC/RC2	90-110	195-225	75- 85	170-190	50- 65	125-150
MC/RC3	110-125	235-255	100-110	210-230	65- 95	150-200
MC/RC4	125-140	255-285	110-120	230-250	80-105	175-225
MC/RC5	140-155	285-310	125-135	255-275	95-120	200-250
Penetration grades						
400/500	160-170	320-340	140-150	290-300	120-135	250-280
280/320	165-175	330-350	150-160	300-320	125-140	260-290
180/200	170-190	340-370	155-165	310-330	130-150	270-300
80/100	180-200	360-390	165-175	330-350	140-160	290-320
60/70	-	-	-	-	150-165	300-330
40/50	-	-	-	-	160-175	315-345
30/40	-	-	-	-	165-190	330-375

Notes:

(1) Owing to the inflammable nature of the solvent in RC type cutbacks the application temperatures of these grades should be kept to the lower end of the ranges quoted.

(2) The temperature range given for each grade is necessarily rather wide because local climatic conditions and the type and condition of the equipment affect the optimum spraying temperature.



If it is desired to provide at the time of construction a pavement capable of carrying more than 0.5 million standard axles, the designer may choose either a 150mm (6in) base with a 50mm (2in) bituminous surfacing or a 200mm (8in) base with a double surface dressing. For both of these alternatives, the recommended sub-base thickness is indicated by the broken line.

Alternatively, a base 150mm (6in) thick with a double surface dressing may be laid initially and the thickness increased when 0.5 million standard axles have been carried The extra thickness may consist of 50mm (2in) of bituminous surfacing or at least 75mm (3in) of crushed stone with a double surface dressing. The largest aggregate size in the crushed stone must not exceed 19mm (¾in) and the old surface must be prepared by scarifying to a depth of 50mm (2in). For this stage construction procedure, the recommended thickness of sub-base is indicated by the solid line.

Fig. 1 PAVEMENT DESIGN CHART FOR FLEXIBLE PAVEMENTS

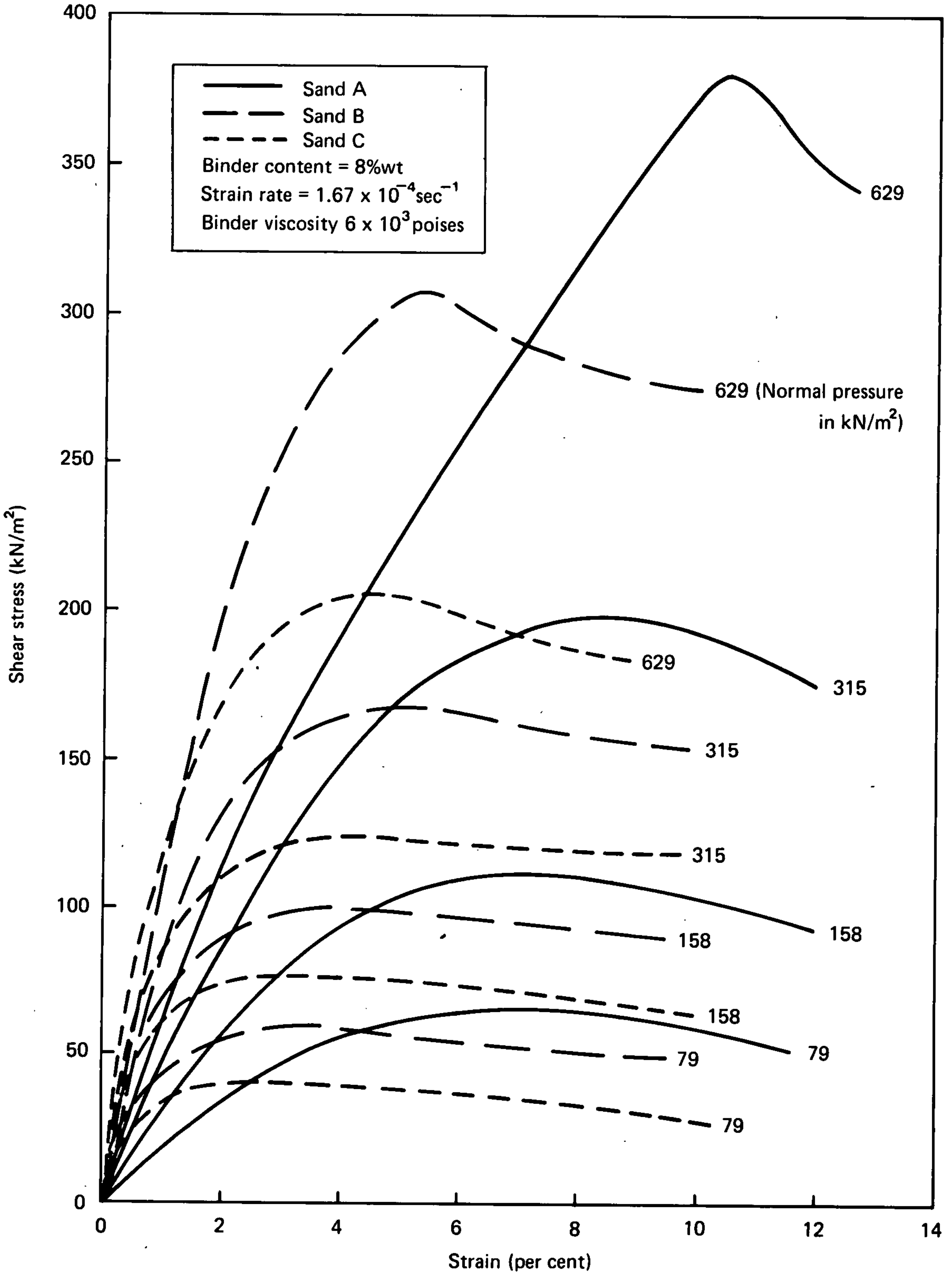


Fig. 2 TYPICAL STRESS/STRAIN RELATIONSHIPS FOR SAND/BITUMEN IN SHEAR BOX TEST

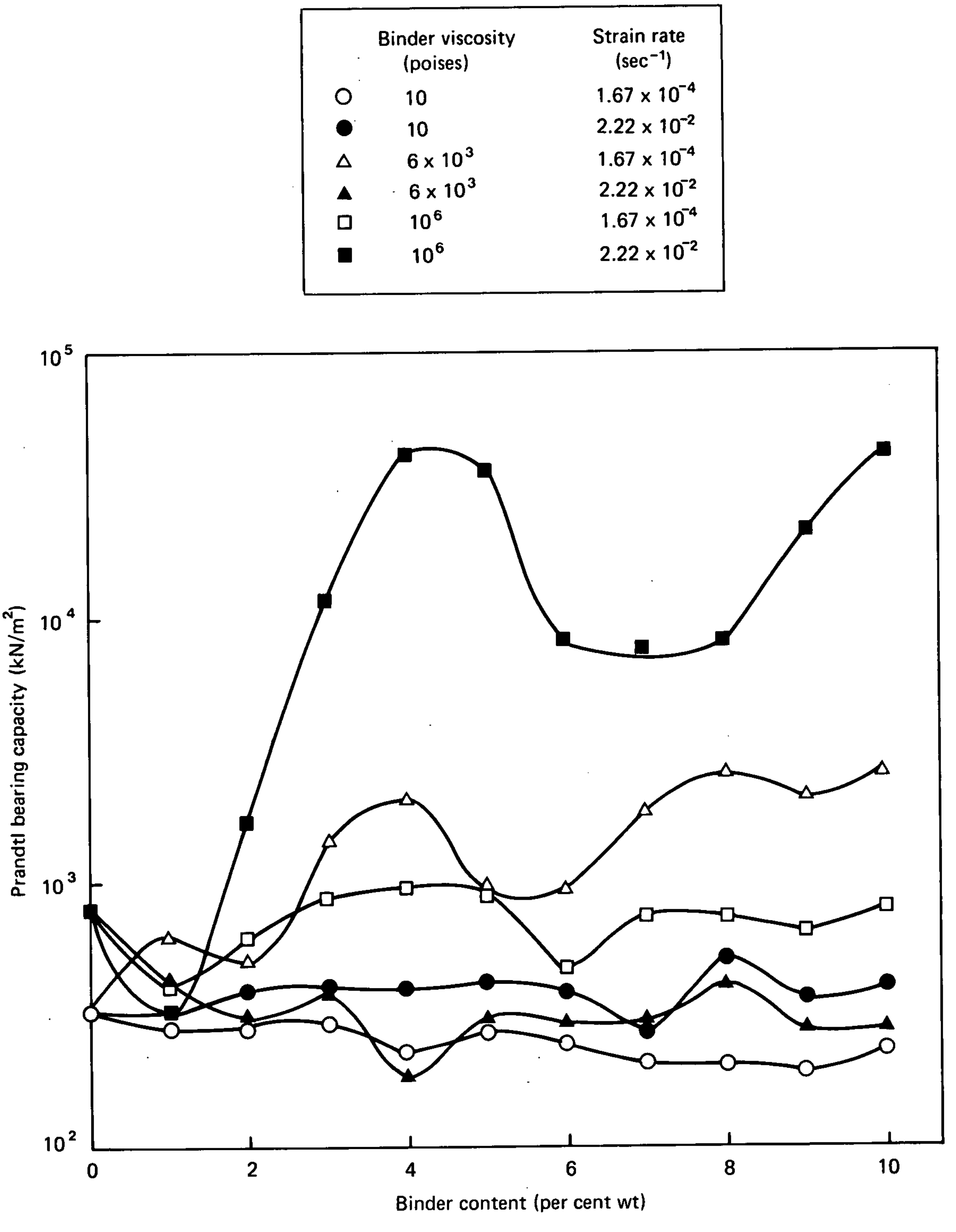


Fig. 3 PRANDTL BEARING CAPACITY VALUES FOR TYPICAL SAND/BITUMEN

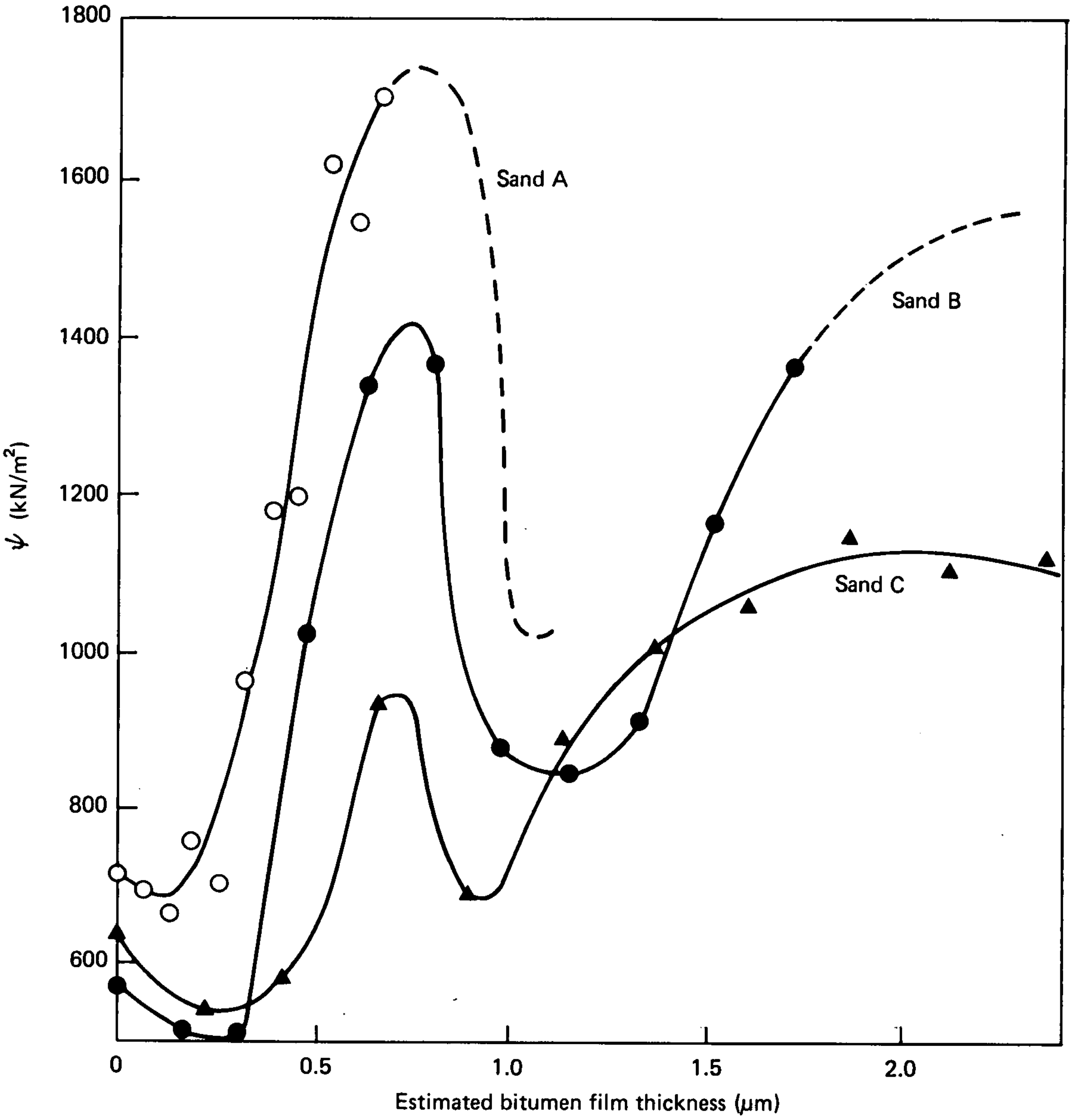


Fig. 4 RELATIONSHIP BETWEEN EBFT AND Ψ AT 2.22 x 10^{-2} SEC^{-1}; 10^6 POISES

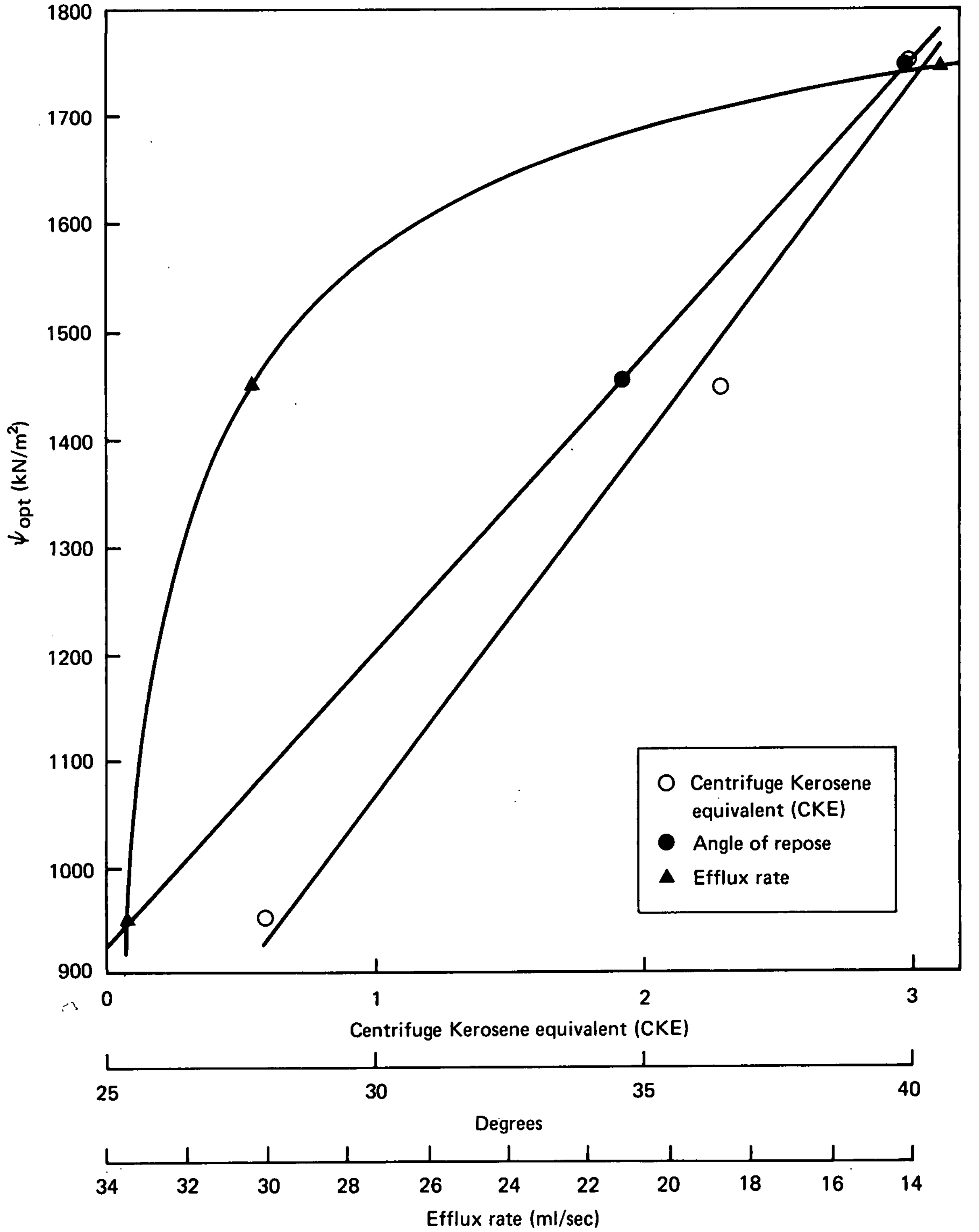


Fig. 5 RELATIONSHIP BETWEEN Ψ_{opt} AND SOME PHYSICAL CONSTANTS OF THREE SANDS (DRY)

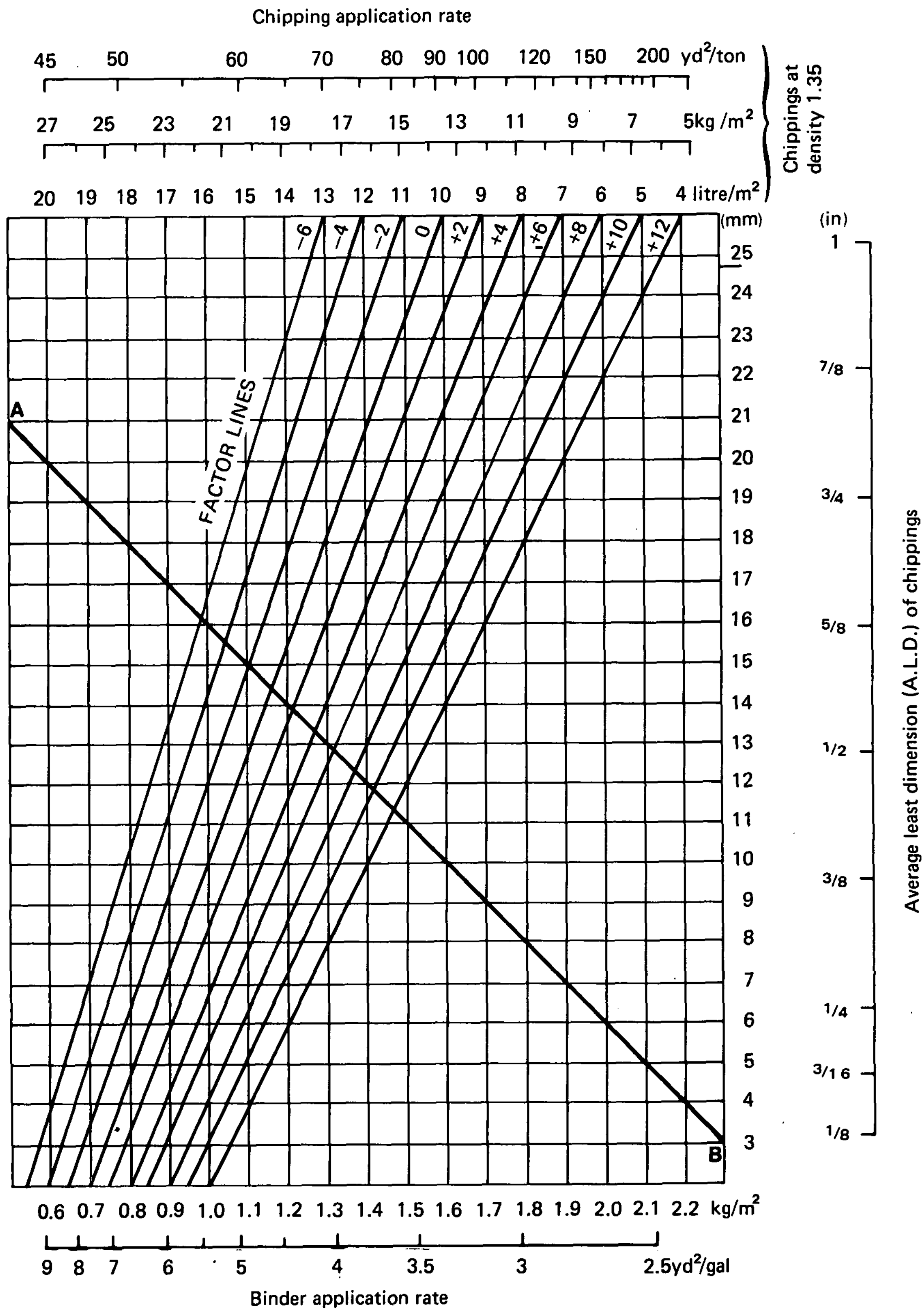


Fig. 6 SURFACE DRESSING DESIGN CHART

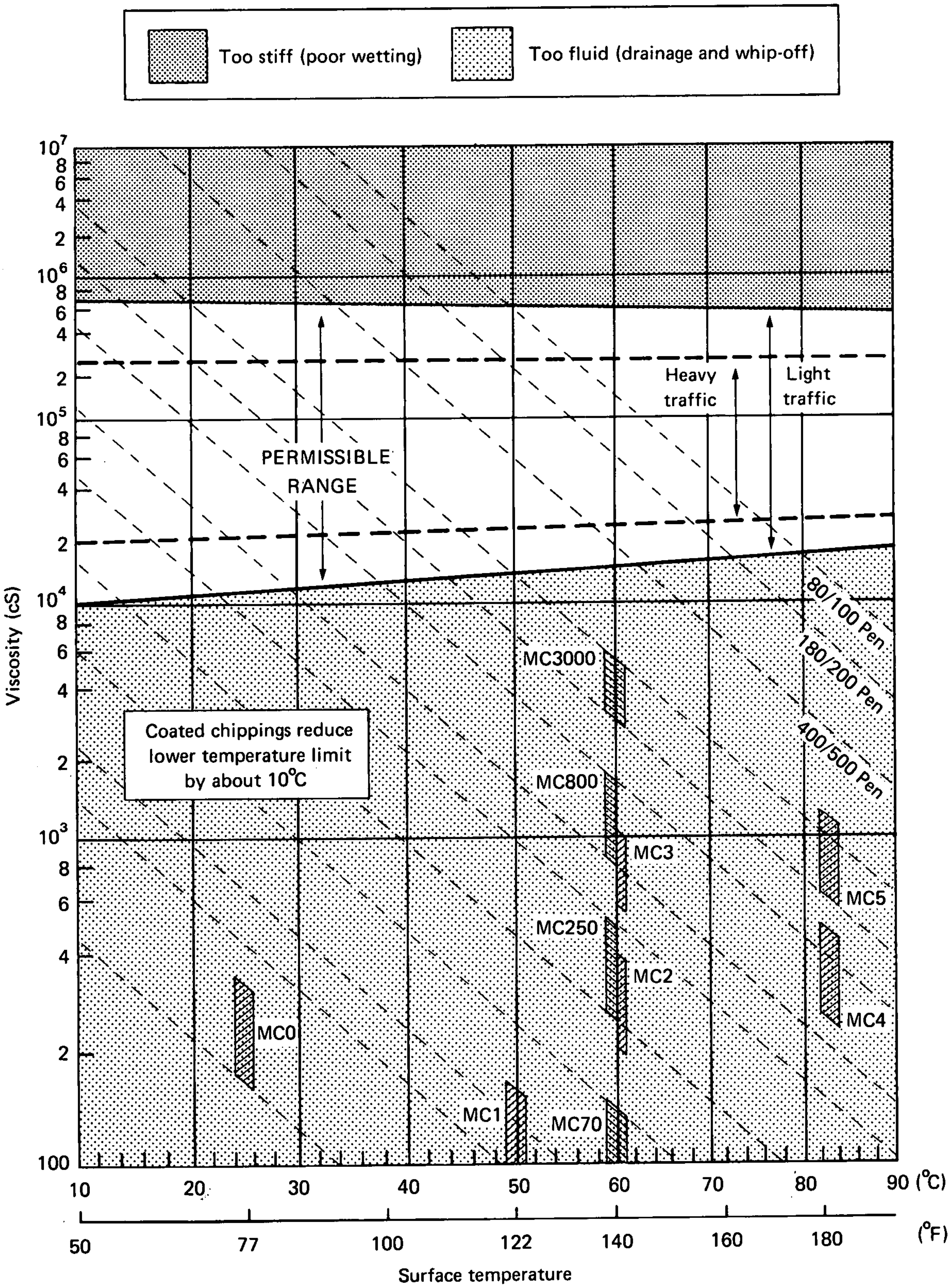


Fig. 7 SURFACE TEMPERATURE / CHOICE OF BINDER FOR SURFACE DRESSING

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ABSTRACT

BITUMINOUS BASES AND SURFACINGS FOR LOW-COST ROADS IN THE TROPICS: *L S Hitch and R B C Russell, BSc MPhil MIHE FGS:* Department of the Environment Department of Transport TRRL Supplementary Report 284: Crowthorne, 1977 (Transport and Road Research Laboratory). Mechanically stable materials for road bases are often not obtainable in developing countries and the technique of soil stabilisation has therefore been developed. In the Middle East, aggregates are often scarce but oil products are readily available. The region has therefore provided some of the earliest examples of bituminous stabilisation, which originally consisted of thin running surfaces over compacted sand. Bituminous stabilisation can also enable local sand to be used for base construction, and various tests and design criteria have been proposed for such applications.

The report describes full-scale experimental trials supported by laboratory research, which have enabled acceptance criteria for bitumen-stabilised sand bases for light/medium traffic to be proposed. Construction methods for bituminous stabilisation are also described.

Details are given of methods of surface dressing, which is important both as an initial running surface on new bases and as a maintenance treatment.

Premixed bituminous materials, both as bases and surfacings, might perhaps be considered as inadmissible for low-cost roads. Such roads, however, usually require progressive improvement because of the traffic growth which accompanies development. There is a growing use of strengthening overlays and the report briefly discusses premixed materials and their application.

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