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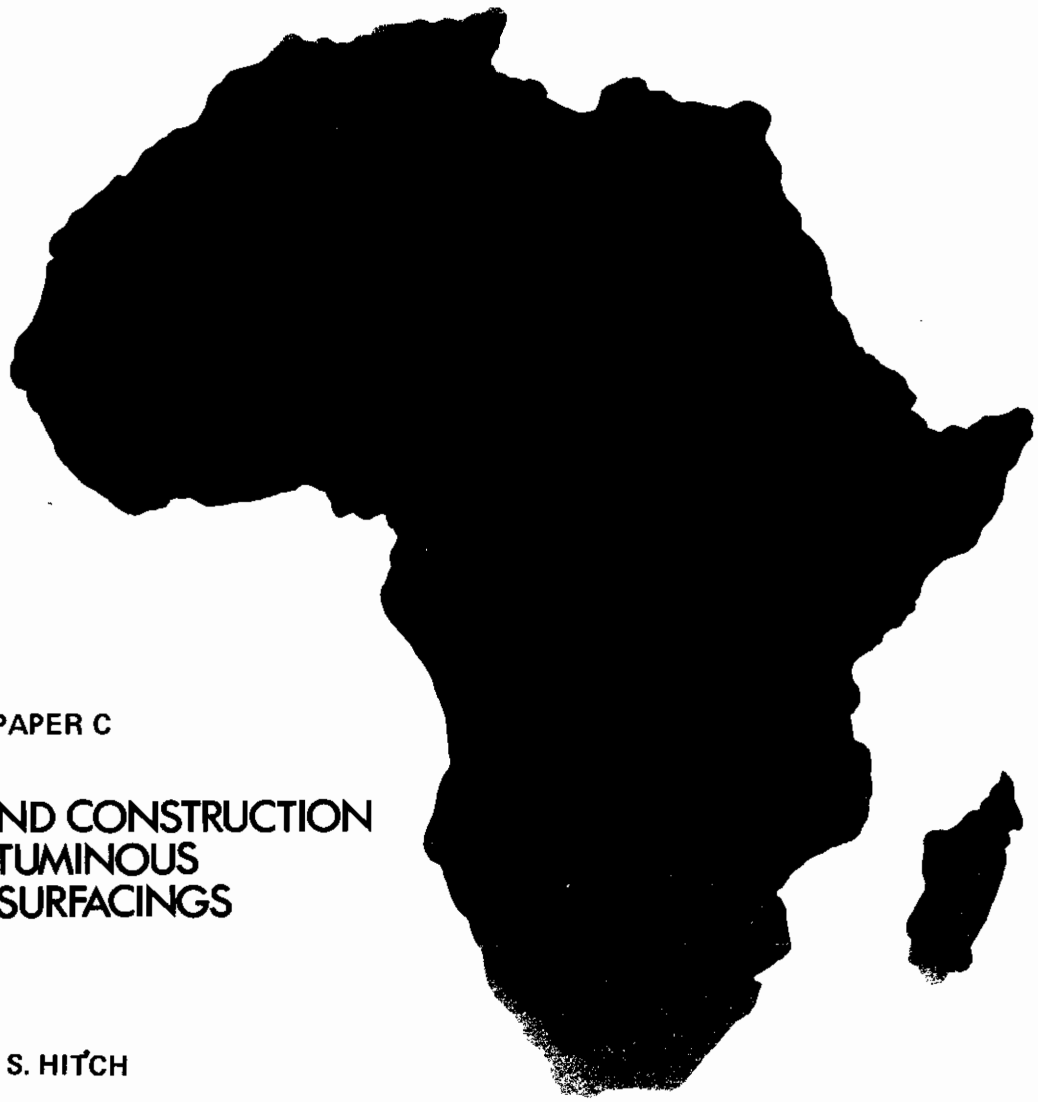

PAPER C

THE DESIGN AND CONSTRUCTION OF BITUMINOUS ROAD SURFACINGS

L. S. HITCH

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THE DESIGN AND CONSTRUCTION OF BITUMINOUS ROAD SURFACINGS

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ABSTRACT

When traffic on earth or gravel roads increases to a certain level it becomes necessary to provide a surface with lower maintenance and vehicle operating costs and without the dust nuisance in dry weather. In the majority of cases the most appropriate form in Africa is provided by a bituminous surfacing, particularly since this allows a stage construction process of economical road improvements to be adopted.

For the first stage a cheap process, a single or double surface dressing (spray and chip treatment) prevents flying dust and surface attrition. The road is sealed against ingress of rain thus maintaining the road structure in a stronger condition with resultant reduction of need for maintenance. The design and technique of construction of surface dressings for African conditions is discussed in the light of experience in Africa, Europe and Australia.

With further increase of traffic the surface-dressed road needs overlaying with a thicker layer of bituminous material which will contribute to the strength of the road by reducing the stresses transmitted to the lower structures (base, sub-base) of the road. Normally mixtures of graded stone and bitumen are premixed in a plant for transport to the road site. The problem for the African engineer is to adapt the design of the many types of bituminous 'premix' developed in industralized, often temperate countries, to suit the different materials available to him and the more extreme climatic conditions of his region.

The two main types of premix - based on continuous or gap-graded aggregate mixtures are described with their advantages and disadvantages. Adaptions to suit African conditions are suggested. Mix design procedures for specifying properties of premix constituents and their application to local conditions are discussed.

For heavy duty surfacings on heavily trafficked roads often in urban areas in Africa the possibilities are explored of using a modified form of British hot-rolled asphalt as an alternative to the almost universal use of asphaltic concrete designed by the Marshall method.

It is concluded that no single ideal and universal solution for the design of any form of bituminous surfacing exists. The challenge for the African engineer of establishing suitable specifications will best be met through analysis of recorded experience and by conducting controlled full-scale road experiments.

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1. INTRODUCTION

This paper discusses some of the ways in which bitumen can be used for road construction in Africa. In the simplest form of surfacing, advantage is taken of the impermeability to water of a thin sprayed film of bitumen which seals the road against rain. Many types of bitumen-aggregate mixture can be used. In these the bitumen acts as a lubricant whilst fluid during the compaction process; later when it cools and stiffens it confers cohesive strength.

The term 'bituminous material'[1] as understood by the road engineer includes tars produced as by-products in the carbonisation of coal, as well as naturally occurring asphalts and bitumen obtained from the distillation of crude petroleum. Tar is usually produced in highly industrialised countries and is not widely available in Africa. Natural asphalts exist but are unlikely to be used by road builders to any significant extent. Accordingly, in this paper bitumen produced by the distillation of crude oil is the only binder considered.

Africa presents a range of material and environmental conditions for the road builder. Some features are, however, common to most territories: principally these are large distances, seasonal high temperatures and arid conditions, and material supplies problems. These problems are usually aggravated by the constraints of annual budgets which tend to limit the extent of new works and levels of maintenance. The resourcefulness of engineers, particularly in the last 20 years, has nonetheless provided much of Africa with a system of primary roads to a reasonable standard. Durable road bases of adequate strength have been constructed, often by some form of soil stabilisation and thus more economically than would be the case in Europe. These economies, however, have been necessary in order to achieve the desired mileage of earthworks, road base, etc, and have permitted no extravagance in the bituminous surfacing. This often consists of a single or double surface dressing to seal the road and reduce attrition by traffic. These dressings, correctly made, are usually adequate in the early life of many roads.

In many countries, on the most important sections of the primary road network, traffic volumes are growing rapidly and often the loading of axles is increasing alarmingly. In these circumstances, overlays of bitumen-aggregate mixtures can provide the necessary strengthening of the road structure. For example, the design chart in the proposed revision of Road Note 31 (Appendix 1) recommends that when surface dressed roads have carried 0.5 million repetitions of the standard axle load, a strengthening overlay of 50 mm of bituminous surfacing will permit a further 2.0 million repetitions.

These bituminous road surfacing layers can themselves be overlaid with similar layers, thus allowing the road to be strengthened in stages which reflect the demands of further increasing traffic. This advantage of bituminous materials in stage construction is not shared by cement concrete which cannot successfully be used as a road surfacing at initial thicknesses less than 125 - 150 mm and is not easily superimposed with further layers of cement concrete. The use of bituminous materials therefore offers the road builder in developing countries the advantage of allocating scarce resources in stages such that investment matches immediate and predictable demand.

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.

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. A TRRL publication[2] gives detailed information on the subject; low viscosity cutbacks of the MC 30 (MC 0/MC1) 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 later.

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 cutback, MC30 (MC0-MC1) 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 pre-mixed 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 which can 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.[3]

3. SURFACE DRESSING

Surface dressing, known also as '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 a part of the initial construction of a new road. Further surface dressings can be applied as a maintenance process: the service life of all forms of premixed bituminous surfacing is extended by the periodic use of surface dressing as a maintenance treatment. Some references[4,5,6,7] are given to the extensive literature on surface dressing.

3.1 Properties

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 stone chippings applied in the dressing surface cannot restore riding quality to an irregular pavement or contribute sensibly to pavement strength.

3.2 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 size 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:

1. 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 are 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 Africa but are included for completeness.

2. Determine the average least dimension (ALD) of the stone; measure the least dimension of approximately 200 chippings. Depending on the supplier, chippings of a given nominal size can have different ALD's; these differences affect the application rates of chipping and binder. The application rate for chippings is found from Table 1 which includes a 10% allowance for 'whip-off'.

TABLE 1 - Application rate for chippings
(see also Appendix 2)

ALD	kg/m^2	yd^2/ton
20 (mm)	27	45
14	19	63
10	14	87
6	8	140

(These application rates will appear to be rather heavier than those normally cited for a given nominal size).

3. Select from Table 2 an appropriate constant from each of the four sets of conditions listed. Sum the four constants to obtain an overall factor and refer to Appendix 2: take intercept of ALD and overall factor line determined above and produce to bottom two scales. Read off binder application rate.

TABLE 2

Traffic	Veh/day	Constant	Type of chippings	
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			**Climatic conditions**	
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

3.3 Choice of stone

Aggregate should be clean, dust-free and should comply with requirements of the type given in BS 63.[8] 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)[9] 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.[10] (see Appendix 3)

Aggregates of high crushing value sometimes show a tendency to polish. Low strength aggregates may abrade and develop surfaces of poor skid resistance;[11] such aggregates are particularly susceptible to crushing when rolled with a steel wheel 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 tend to 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, a useful alternative often used is to pre-treat the chippings with a very small amount (0.5% 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 later). Chippings must be capable of being spread by standard gritting machinery and must not therefore 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 cutback can be used. The above treatments are not recommended when surface dressing with bitumen emulsion.

3.4 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.

Appendix 4 shows the viscosity/road temperature relationship for a wide range of binders. It will be clear that for most African conditions suitable surface dressing binders will be MC3000 (MC4/MC5 or similar, eg S125) 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. 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%
3. Suitable source of supply, transportation and storage.

African conditions, particularly Central and Northern, are predominantly dry and dusty and do not therefore favour the use of emulsions which are better suited to cool and damp conditions. For this reason special cationic emulsions of higher viscosity and containing 70-75% 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% cationic emulsion as used in South Africa[12] 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.[12] 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 surfacing dressings - but the Engineer should be aware of the problems cited above that can arise. Careful attention to technique of application is needed.

3.5 <u>Equipment and processes</u>

Construction methods for surface dressing are adequately described elsewhere;[4,7] attention to detail and good planning will ensure success.

3.5.1 <u>Equipment</u>. 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).

3.5.2 Processes. 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.

3.6 Adhesion agents

The use of adhesion agents in surface dressing (and bitumen pre-mix) 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-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% 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 in Africa. When it is difficult to obtain dust-free chippings the light-coating treatment for chippings described earlier may be an economical alternative to the use of adhesion agents.

3.7 Surface dressing research in Africa

Surface dressing is well established in Europe against a background of extensive research over many years. The adaptation of the technique to the very difficult conditions in Africa still poses problems. Many African countries have their own surface dressing specifications but a general exchange of information would be useful and further research is needed. Some suggestions for this research are:

1. A study of the relative effectiveness of different binders for different environmental conditions, eg effects of climate, season and traffic.

2. Studies to correlate the surface dressing performance of certain aggregates, especially weak ones, with aggregate properties, eg ACV, impact value, PSV etc.[9]

3. An examination of the effect of aggregate size on performance.

4. SLURRY SEALS AND GROUTED MACADAMS

These materials may be considered as intermediate between surface treatments and premixed materials with respect to cost and performance.

4.1 Slurry seals

These are basically mixtures of fine aggregate, water, bitumen emulsion and occasionally cement. Where new seals have to be opened to traffic within a very short peruod, 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. They are particularly useful for re-sealing aerodrome runways[13] and standard reference works[14] are available. 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'.

4.2 Grouted and semi-grouted macadam

Where suitable mixing plant is not available, macadam (see later) can be constructed by grouting; this involves rolling a layer of stone, applying binder to fill or partially fill the interstices and then applying further stone of smaller size. This constitutes a semi-grout; a second application of bitumen and a third application of chippings constitutes a full grout.

Table 3 gives typical full grout specifications for a surfacing course.

TABLE 3

Bitumen-grouted surface course (Ministry of Works, Kenya)

Application Rate of spread Grading	Nominal course thickness 40-60 mm			Nominal course thickness 60-100 mm		
	Coarse aggregate	Choke	Seal	Coarse aggregate	Choke	Seal
	1st	2nd	3rd	1st	2nd	3rd
Bitumen application (at 15.6°C), $1/m^2$ per 10 mm thickness	-	0.87	1.27	-	0.87	1.71
Aggregate		12	10	60		12
Nominal size mm Rate of spread m^2/m^3 per 10 mm	40	100	109	52		82
thickness	52					
Grading:						
% passing B.S. Sieve						
76.2 mm (3")				100		
63.5 mm (2½")				90 - 100		
50.8 mm (2")	100			35 - 70		
38.1 mm (1½")	90 - 100			0 - 15		
25.4 mm (1")	20 - 55			-	100	
19.0 mm (¾")	0 - 15	100		0 - 5	90 - 100	100
12.7 mm (½")	0 - 5	90 - 100	100			85 - 100
9.5 mm (3/8")		40 - 70	85 - 100		20 - 55	0 - 22
6.4 mm (¼")		-	0 - 25			0 - 7
4.8 mm (3/16")		0 - 15	0 - 10		0 - 10	-
No. 7		0 - 5	0 - 2		0 - 5	0 - 2

Note: Specified binder normally 80 - 200 penetration grade.

Penetration grades of bitumen, cut-backs and emulsions are all used for grouting. The binder used, however, must penetrate and coat the aggregate layer to the depth required; for full grouts this is the total depth but, when semi-grouting with emulsions, up to two-thirds of the total depth of compacted stone is water-bound. This is achieved by watering the aggregate during construction; the cushioning layer of fines upon which the aggregate is spread eventually rises during compaction to the required height thus preventing the emulsion from draining too deeply into the layer.

Despite its apparent simplicity, grouting is not a cheap substitute for premixed macadam for the following reasons:

1. Relatively large amounts of bitumen are required and it can be calculated that a full grout (7.5 cm approx) requires 30% more bitumen than the same depth of bitumen macadam.

2. Grouting involves more operations than in premix construction.

3. Because of construction techniques, grouted work is unlikely to have the surface regularity of paver-laid premix.

5. BITUMINOUS PREMIX: THEORETICAL BASIS

Perhaps the most important question on this subject is the one most often neglected, namely, 'what is being attempted?'. The answer depends largely on the contribution expected of the binder; it can act as adhesive, sealant and lubricant. It is hoped that the present discussion will contribute to rational selection of premixed compositions.

5.1 Fundamental requirements

Premixed bituminous materials must possess one or more of the following properties:

1. Resistance to deformation; 'stability' can be measured by several empirical tests.[15] Lack of stability causes rutting and pushing under traffic stresses.

2. Cohesion; at least one empirical method due to Hveem[15] is available. Lack of cohesion causes cracking and attrition by traffic.

3. Tensile strength; not normally measured as such. Maupin[16] concludes that it should be possible to use the indirect tensile strength test to assess fatigue susceptibility in asphaltic mixtures. Marais[17] concludes that the correlation between Marshall stability[15] and indirect tensile strength is such that fatigue resistance of gap-graded mixtures (and doubtless others) can be controlled by imposing an upper limit on Marshall stability. The tensile strength of practical mixtures must therefore lie between limits; very low values will characterise mixes lacking cohesion whilst very high values will indicate mixes of correspondingly high stiffness but low flexibility, possibly susceptible to cracking.

4. Impermeability; values are not normally specified and indeed some mixes are very permeable, Table 4 shows typical results. If necessary, permeable mixtures must be surface dressed or slurry sealed.

TABLE 4

Typical water permeability values for some bituminous premixes

Bituminous premix	Soil type of similar permeability	Permeability (30 cm water head) cm/sec	ft/day
Macadam wearing course open textured (BS 1621 Table 3) i. as laid ii. trafficked	sand	10^{-3} 10^{-6}	3 0.003
Macadam wearing course, dense (BS 1621 - Table 5) trafficked	sandy-clay	10^{-6}	0.003
Rolled asphalt wearing course BS 594 Schedule I: i. 30% stone 8% bitumen ii. 55% stone 6% bitumen	clay -	10^{-8} 10^{-4}	3×10^{-5} 0.3
Asphaltic Concrete (1 yr old) Bitumen content (mean)(%) 6.1 6.5 7.0 7.6	- - - -	7×10^{-6} to 2×10^{-8} 2×10^{-6} to 1×10^{-8} 6×10^{-6} to 8×10^{-9} 4×10^{-7} to 8×10^{-9}	) Some samples) had hair) cracks)

Note: For UK and very wet conditions overseas) desirable condition = 10^{-8} cm/sec
with prolonged rain, no sun and much shade)

Where rain is heavy overseas but lasting only) desirable condition = 10^{-5} cm/sec
up to one hour and sun within 12 hours

5.2 The basis of mix composition

Fundamental mix requirements already introduced are now discussed in relation to composition.

5.2.1 Stability. Stability can be obtained from two types of mix:

i) A system of durable, interlocked particles; John Loudon Macadam pioneered such systems in the late 19th century with stones being keyed by wet-placed fines. This material, known as waterbound macadam, is still in use for many road bases but bituminous binders are now used and act as lubricants during compaction but adhesives thereafter. Stability comes from aggregate interlock.

ii) A stiff mortar. Stiffness is a function partly of binder viscosity and is therefore dependent on temperature and filler/bitumen ratio; bitumen is again an adhesive but also a sealant.

5.2.2 Cohesion. Cohesion depends largely upon the adhesive properties of bitumen and the following are important:

a) Bitumen percentage must be sufficient to coat aggregate completely.

b) Adhesion is poor if binder viscosity is too low or too high.

c) Bitumen must not strip from aggregate: an adhesion agent may be necessary for difficult aggregates, eg quartzites used in compositions permeable to water.

d) The area of coated aggregate in interfacial contact, and thus transmitting applied forces, should be as large as possible; this calls for a dense mix.

5.2.3 Tensile strength. This is a measure of the cohesion and the same criteria apply.

5.2.4 Impermeability. Bitumen must seal the material completely. Aggregate voids must be low, requiring therefore a dense mix. Surface area of aggregates will be high requiring high binder contents. A controlled volume of discontinuous air voids will exist in the mix as laid, thus permitting compaction under traffic without bleeding, but preventing water from permeating the mix.

6. PREMIXED BITUMINOUS MATERIALS: PRACTICAL MIXES

In the two basic types of mix already described (Section 5.2.1) the bitumen is required to act differently and selection of grade is important. Choice is affected by the mix function (base, binder course or surfacing), climate and construction technique.

6.1 Interlocked aggregate mixes

6.1.1 Macadams. Macadams in various forms are interlocked aggregate mixes: existing specifications include road bases[18] as well as surfacings.[19] Crushed aggregates must be used but, so that compaction can occur, stones must move to some extent relative to each other during construction and for this reason viscous resistance is controlled. For UK usage, BS 1621[19] permits a viscosity range from 30 sec (STV) at 30°C to 90 penetration grade. In Africa the range would probably be from MC3000 (MC5) to 60/70 pen). During service the bitumen acts as an adhesive but because of the relatively large air voids it cannot act as a sealant.

All macadams must be considered as pervious to water. Particularly if they overly a permeable road base or other pavement layers which are weakened by soaking, they should be sealed by a surface dressing. Air can enter these mixes and hardening of the binder will occur. This hardening is caused by oxidative embrittlement of the binder and is more rapid at the high temperatures encountered in black-top surfacings in the tropics. Macadam compositions in the UK have evolved from many years of experience and laboratory mix design is not used.

6.1.2 Asphaltic concrete. This term has become associated with an interlocked aggregate mix type of high quality; it can probably be regarded as the ultimate macadam since the sizes of interlocking particles decrease steadily from coarse aggregate to filler, giving a continuously graded mix. The air voids in the compacted graded aggregate are approximately 17-20 per cent by volume. Since a typical specification for the voids in freshly compacted asphaltic concrete would be 3-5 per cent by volume, it follows that only some 12-14 per cent of the voids in the mixed aggregate are available for bitumen. This is often equivalent to a bitumen content of only 4.5-5.5 per cent by weight. Because of the high surface area of the stone to be coated, the binder film is very thin. Of the several methods of mix design currently available the one due to Marshall[15] is most widely used. The mix design exercise establishes an optimum bitumen content corresponding to specified values of strength, resistance to deformation (flow) and controlled air voids.

Some users of the Marshall mix design method attach too great an importance to the production of mixes with maximum stability; the corresponding flow values of such mixes, as measured by the Marshall method, are likely to be such that they lack flexibility. Jackson and Brien[20] suggest that permanent deformation of the mix can be prevented provided that:

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

This imposes a minimum value on stiffness; experience at TRRL is that mixes produced in the developing countries have usually an unnecessarily high stiffness. Marshall design criteria for road surfacings in the tropics have been calculated for three traffic types on the basis of assumed tyre pressures, permissible flow values and the minimum stiffness proposed earlier. Results are shown in Appendix 5. Maximum stability is often sought with no regard to mix durability for which adequate binder is required. High stability values are often obtained by using the highest prescribed level of compaction, ie 75 blows, in the Marshall test; the optimum bitumen content derived on this basis tends to be lower than that for 50 blow compaction, which represents a density nearer to that commonly achieved in the field. The subsequent success of such mixes will depend upon the efficiency of compaction during construction, since it is essential that the design density should be achieved if the performance of the mix is to reflect the laboratory test. If design density is not achieved the finished carpet will be pervious to water and air, and the thin binder coating on the aggregate will undergo weathering action, resulting in hardening and eventual brittle failure of the material; hardening of the binder occurs in any case during the mixing and laying process. Over-heating of the aggregate in the mixing process will harden the binder severely thus shortening the life of the surfacing. Bright and Reynolds[21] investigated the effect of mixing temperature on bitumen in the range 85-100 penetration, commonly used for asphaltic concrete and normally mixed at 140-160°C:

Mixing temperature °C	Retained penetration (per cent)
145	60
175	50

It is not always appreciated that failure to produce the design composition in any respect, ie aggregate grading, bitumen or filler content, will disturb the overall behaviour of the mix. In particular, bitumen content is fairly critical and a typical requirement would be for control to within ± 0.3% by weight of the design optimum. Failure to observe this could result in:

either a) lean mixes, dry and lacking cohesion: failure by attrition or by cracking,

or b) rich mixes, voidless and with excess bitumen action as a lubricant: failure due to rutting and pushing; surface slippery.

Experience shows that good service is more likely to be obtained when asphaltic concrete receives constant trafficking: deterioration is common when it receives no traffic.

These comments are not intended to dismiss or devalue asphaltic concrete; any mixed material requires a degree of care in preparation. The position is perhaps best expressed in terms of realism, ie a realistic appraisal of the manufacturing process is essential, inter alia, if asphaltic concrete is to be used successfully. The completion of the laboratory mix design is only a beginning and requires effective translation into plant job mix formula and subsequent strict control of production. In this paper it is only possible to discuss some aspects of asphaltic concrete behaviour; much published work exists and some references are given.[22,23,24] The applicability of asphaltic concrete to Africa is dealt with later.

6.2 Mortar type mixes

These mixtures can be traced back to approximately 1870: A Belgian chemist DeSmedt used hot fluxed natural asphalt to coat hot sand, to produce sheet asphalt surfacings. Clifford Richardson examined the effect of sand grading on these surfacings in America and in 1896 his recommendations were implemented in London with success: the resulting mortar type mixes, known in the UK as rolled asphalt, have remained basically unchanged since that time. Mastic asphalt[25] which is used for bridge deck surfacings, bus stops, roofing, etc is also an extreme example of a mortar type mix but is very expensive and difficult to lay by machine. Its use is declining in Europe and it is unlikely to find economic appreciation in Africa.

6.2.1 Rolled asphalt. Rolled asphalt depends on the stiffness of a sand/filler/bitumen mortar for its structural strength. Stiffness is obtained by the use of a relatively hard bitumen, 40/60 or 60/80 pen. Hot sand is coated with this binder, and filler is added in order to increase the effective viscosity, the end product being a very stiff mortar. Stone has not so far been mentioned and indeed in the days of Richardson none was used. The relevant British Standard, BS594:1961,[26] (but see Section 9) will be found to include mixtures with no coarse

aggregate: added stone acts as an extender and above a certain proportion adds to the stability of the mix. The practice of specifying the gradations of stone (retained on No 7 sieve) and sand (No 7 - No 200 sieves) separately has the effect of creating a discontinuity in the grading of the combined aggregates; rolled asphalts are therefore often referred to as 'gap-graded'. As one would expect, such a material has a high tensile strength, which increases with increasing hardness of binder. The contribution to the strength of the pavement is considerably greater than that of macadam type mixes. Rolled asphalt may be considered as impermeable and can thus effectively seal the pavement structure; however, in order to provide a non-skid surface, chippings coated with approximately 1½ per cent of bitumen have to be spread and partially embedded into the surface of rolled asphalts containing less than 45 per cent of stone. Spreading is best carried out by special machine which follows the paver during construction. The resistance of rolled asphalt to deformation under traffic will be affected adversely by high temperature and most probably it is because excessive deformation is feared that it has not hitherto been considered seriously as a surfacing applicable to the tropics. However, some successful work has been done in South Africa,[27] and the Overseas Unit of TRRL has carried out two surfacing trials, one in the Arabian Gulf and the other in Turkey: other experimental surfacings will be constructed when possible in order to establish which, if any, of the current BS594 compositions would be applicable, with or without modification, to given tropical environments.

Like macadams, rolled asphalt compositions and their performance have become established with experience; they are receipe mixes requiring no laboratory design procedures but depending upon the use of tightly controlled specifications for the sand fraction in the mix. The Marshall test procedure has recently been applied to the study of rolled asphalt mortars at TRRL, the objective being to determine an optimum bitumen content for the sands conforming to the requirements of BS594 and also for sands or crushed rock fines not conforming to these requirements. (See Section 9). Similar research has been done by Duthie.[28] Other research at TRRL includes a comparison between Marshall test values and deformation resistance as measured by the deformation wheel-tracking test.[29] Marais[17] and Brien[30] have also assessed this technique in relation to rolled asphalt performance.

6.3 The selection of surfacing compositions for Africa

The composition and characteristics of different mixes have already been discussed; the effect of temperature will be of the greatest importance in selecting suitable surfacing mixtures for Africa. Macadam compositions are relatively unaffected by heat: dense bitumen macadam, eg to BS1621 Table 5,[19] is a possible choice where high road temperature and/or heavy traffic are expected. It will be found that this material closely resembles asphaltic concrete; grading is however less dense than for asphaltic concrete and because of the higher aggregate voids a thicker bitumen film can be provided than for asphaltic concrete without the risk of fatting up in service. It will be more flexible than asphaltic concrete: the thicker binder film will be less susceptible to hardening by atmospheric oxidation and will most probably have at least the same service life.

One drawback must be noted: macadam will be pervious and, if rainfall is a problem, will need to be surface dressed.

Asphaltic concrete can and often does perform excellently; it must be stressed however that its use should only be attempted where:

1. Angular screened aggregates and filler are available
2. Weigh batch type mixing plant will be used
3. Meaningful and rapid plant control is available
4. The completed surface will receive frequent traffic: asphaltic concrete may perform well in city streets but very poorly on infrequently trafficked roads.

The use of rolled asphalt in South Africa was mentioned earlier,[27] where a filler bitumen ratio of between 1 and 2 is specified. The surfacing trial in the Arabian Gulf, referred to earlier, has been under traffic now for 3 years including two hot summers: macadam to BS1621, Table 5, is in good condition and rolled asphalts of 45 and 50 per cent stone content, whilst rich in appearance, have not deformed noticeably, although 60/70 pen bitumen was used (40/50 is used in UK) and filler/bitumen ratios were lower than those specified.

The evidence suggests that rolled asphalt could be used for many surfacing requirements in Africa with the possible exception of some heavily-trafficked roads, particularly where vehicle flow is channelised. Table 5 shows some other typical premix specifications, and Table 6 a specification for gap-graded bituminous overlay as used in Natal, South Africa.

TABLE 5

Typical specifications for bituminous premix

Authority	Shell International Petroleum Co		British Standard 4987 (see Section 9)			
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 3 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) 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)
(% wt total mix)) 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) directio

TABLE 6

Gap-graded overlay specification, Natal, South Africa.[27]

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 ($8-18\times10^{-2}$ 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

7. MATERIALS

Specifications for mixed materials also define to some degree the properties of the constituent materials. It is usually found that bitumen properties are closely defined whereas aggregate properties are hardly mentioned.

7.1 Aggregates

Comparatively little research has been done which relates aggregate properties to performance of the mix in road service. Aggregate availability is frequently a problem and indeed conservation is needed in Europe. Aggregates can often be accepted or rejected with confidence but disagreements occur in the matter of appropriate values for aggregate properties such as strength and abrasion resistance. Table 7 summarises some current recommendations from several sources for aggregate use, but much more information is needed on the relationship between test properties and road performance.

The problem of providing adequate skid resistance on British roads has received particular attention by the TRRL for many years.[31] Inter alia, the dependence of skid resistance upon aggregate properties has been established for stone in direct contact with vehicle tyres. The Polished Stone Value test (PSV)[9] and recommended values for different site conditions have already been mentioned (see section 3.3 also Appendix 3).

The skidding problem in Europe is associated with heavy traffic and wet-weather conditions. On the drier and more lightly-trafficked roads of Africa there is at present probably less danger of skidding accidents. However, little is known of the polishing behaviour of aggregates in hot, dry climates and research is needed to elucidate the problem of providing adequate skid resistance in hot, dry conditions.

TABLE 7 - Specifications/recommendations for bituminous surfacing aggregates

	MOT[18] (UK)	Jackson and Brien[20]	O'Reilly and Millard (TRRL LR 279)	Asphalt Institute Spec SS-1	ASTM D.692-69	Main Roads Dept Queensland (Australia)	NAASRA (Australia) (see note)	Kenya	Malawi
Use	Pre-coated chippings	Asphaltic concrete	Surface dressing	Surfacing	Surfacing	Surface dressing	Surface dressing	Surface dressing and premix	Surface dressing
V (BS) ax)	-	23	35	-	-	20 (>150cvpd) 30 (<150cvpd)	-	22 (s/dressing) 25 (premix)	25
% fines (BS) (min)	-	-	8	-	-	-	-	-	-
gregate (max) rasion (BS)	10 difficult 12 average (sites)		-	-	-	-	-	-	-
gregate (max) rasion os Angeles)	-	25	-	40	40 (wearing) 50 (basecourse)	-	18 (>1500vpd) 27 (300-1500 vpd) 30-35 (<300 vpd)	28 (s/dressing 30 (premix)	-
V (BS) (min)	62 difficult 59 average	-	60 (difficult) 45 (average)	-	-	-	-	-	-
akiness (max) dex (BS)	-	-	-	-	-	35	35	-	-
undness (max) odium or gnesium lphate)	-	-	-	-	12 (sodium) 18 (magnesium)	-	-	12	-

Notes 1. NAASRA = National Association of Australian State Road Authorities
2. BS = British Standard 812[9]
3. Los Angeles = Los Angeles Abrasion Test (ASTM C.131)
4. cvpd = commercial vehicles per day
5. ACV = aggregate crushing value

7.2 Bitumen

British Standard 3690[32] contains specifications for penetration and cutback grades of bitumen suitable for use in the UK. The standard recognises that these may not be directly applicable overseas and does not in fact include certain cutback bitumen types which are much used in the tropics, ie low viscosity cutbacks of the RC/MC type specified by the Asphalt Institute of America;[33] Appendix 6 shows viscosity ranges of both traditional and current American cutback grades.

The earlier discussion includes guidance on selection of appropriate viscosity grades of bitumens for different applications; it must be stressed that it is not practicable to substitute inappropriate grades simply because these are the only ones available. In such cases the process must be changed and the behaviour of the bitumen carefully considered. As an example, it would clearly be inappropriate to use MC or RC3000 (RC/MC5) for surface dressing with chippings at road temperatures higher than 50°C (see Appendix 4) if the road is to be trafficked immediately. The road would have to be closed to allow cutback volatiles to escape and viscosity to increase.

The chemical properties of a bitumen control its durability and resistance to weathering. In the UK there is general agreement that the mechanical properties of the bitumen binder are more important for most road applications than the chemical properties. However, what is true in the temperate climate of the UK may not be true in the more extreme climatic conditions of many parts of Africa. In any case, bitumens used in Africa may be produced from crude oils different from those used in Europe and the chemical natures of these bitumens will be different. Here again there is a field for research - at least for collection of information on the hardening of bitumen in road surfacings and its effect on performance.

8. BITUMINOUS CONSTRUCTION: EQUIPMENT, OPERATION AND CONTROL

8.1 Equipment

Excellent construction equipment is available for all bituminous road processes. Recent developments in surface dressing equipment were mentioned earlier; this equipment is relatively cheap compared with sophisticated premix plant. Prices from a recent British quotation were as follows:

Item	£ sterling
Mobile asphalt plant (90tph)	61,000
Bitumen distributor (1500 gallon) and forward-control chipping spreader	14,000

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'[34] 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 cutback 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 cutback grade will be determined by prevailing aggregate temperatures. The process is used extensively in bituminous stabilisation for bases and will doubtless be applicable to Africa in remote areas. Control of mix proportions in this process is poor.

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[35] and occasionally coated materials, for which a cutback 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 dry/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 cán be produced effectively with such plants, it is not operationally feasible to produce dense mixtures using batch-heater plants.

8.2 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 size, 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. The effect of overheating on retained bitumen penetration has been dealt with earlier; appropriate binder temperatures are given in Appendix 7.

4. The paver must be well maintained, particularly the hydraulic system: pressure failures will allow the screed to fall, thus affecting carpet thickness. 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 point, cleanliness of rolls (or tyres), efficiency of cleaning mats and water spray bars are particular points requiring supervision.

The above are intended as relevant useful comments; some very common faults have been highlighted. Time spent in training supervisory staff is well worthwhile. There is adequate published work on the operation and maintenance of bituminous construction plant and some references are given.[1,20,24,36,37]

8.3 Control of production

Quality control commences before the mixing process; the following checks are particularly necessary:

1. Gradations of aggregate stockpiles.
2. Aggregate properties[9]
3. Filler properties[9]
4. Binder properties[38]
5. Laboratory mix design, if required.

During production the following should be checked regularly:

1. Gradations of hot bins
2. Binder temperature
3. Aggregate temperature
4. Mix temperature
5. Mix composition.

8.4 Control of mix composition

British Standard 598:1958[39] describes several methods for sampling of bituminous materials and sampling at the mixing plant is preferred. The standard is due to be re-issued shortly and it is expected that preference will now be shown for sampling from below the paver screws at the laying site. This procedure

is possibly more meaningful in that effects of segregation during mixing or discharge will have been reduced by the subsequent movement, although provided that mixers are in good condition, samples properly taken at the mixer should show little difference from those at the laying site. Several methods are available for mix analysis: the most effective for control purposes is the sieving extraction method developed at TRRL and described in BS598, method D. A complete analysis is usually possible in 1½ hours and modified conditions established by Hitch[40] enable trichloroethylene to be used with this method in the tropics. Hardman[41] has applied statistical methods to be problem of compliance with specification and has proposed a system whereby work of acceptable quality will be guaranteed for 95% of the time over a long period.

9. RECENT REVISIONS OF RELEVANT BRITISH STANDARDS

Shortly before this paper was printed, the following revisions of relevant British Standards were published:

i) BS 4987:1973. Coated macadam for roads and other paved areas. This Standard replaces British Standards 802, 1241, 1242, 1621,[19] 1690 and 2040.

(Four compositions from BS 4987 are included in Table 5).

ii) BS 594:1973. Rolled asphalt (hot process) for roads and other paved areas.

The Standard now includes a design method which uses Marshall-type equipment.[15] The optimum bitumen content of a fine aggregate/filler/bitumen mortar may be determined and from this the working bitumen content may be calculated, knowing the stone content and type to be used. It should be stressed that the method is stated to be tentative at present and may only be used after mutual agreement between supplier and purchaser. Naturally, since there has so far been no opportunity to relate the performance of rolled asphalt designed by this method to laboratory design data, recommended values for stability, flow and voids cannot yet be given.

10. RESEARCH ON BITUMINOUS MATERIALS IN THE TROPICS

The Overseas Unit at TRRL is currently evaluating different mix types, principally rolled asphalt by full-scale trials overseas and correlating performance with laboratory design methods. There is need for more full-scale trials in which TRRL would assist if invited; the author hopes that governments will conduct their own trials. Mix type, material properties, traffic and temperature all affect the life of a surfacing and require study.

The Marshall test whilst of considerable value in design cannot entirely predict behaviour under traffic; simulated tests such as the deformation wheel-tracking method should be more widely applied and correlated against the Marshall test.

Road binders harden during service and can become brittle resulting in brittle fracture of the mix under certain conditions. Some information is occasionally obtained as a result of failure investigations but a wider and more detailed study is needed. The histories of different mix types containing appropriate binders should be traced: viscosity of binder recovered from mixed material[42] should be determined at say 1 year intervals. If possible a study of changes in chemical constitution should supplement this information.

The results of such studies would give much information on the effect of mix type, binder grade, road temperature, voids etc on binder hardening and would supplement routine studies of pavement strength by the deflection beam.[43]

Finally it is to be hoped that governments will, by their own researches, establish local specifications which reflect local climate, materials and traffic.

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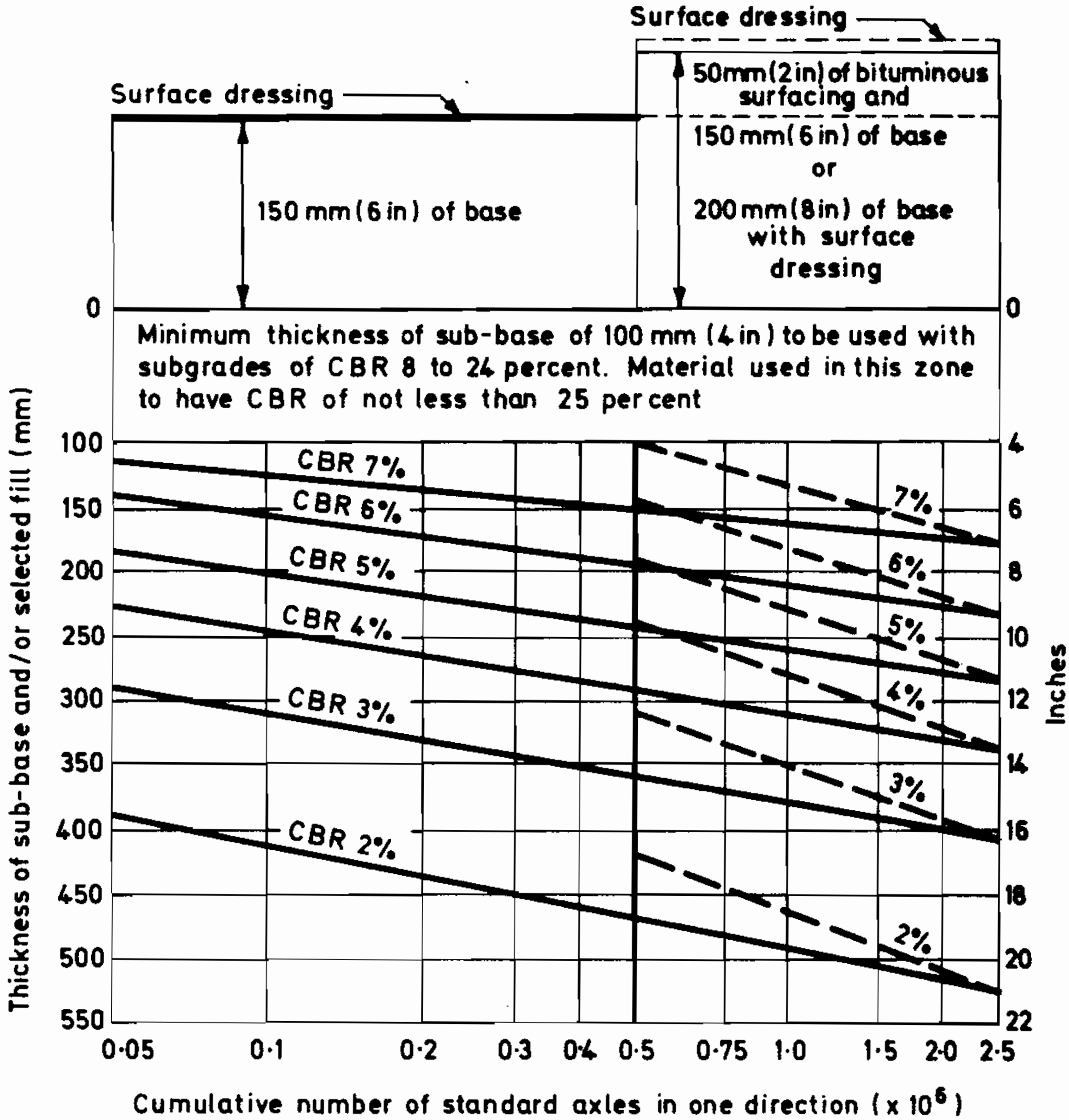
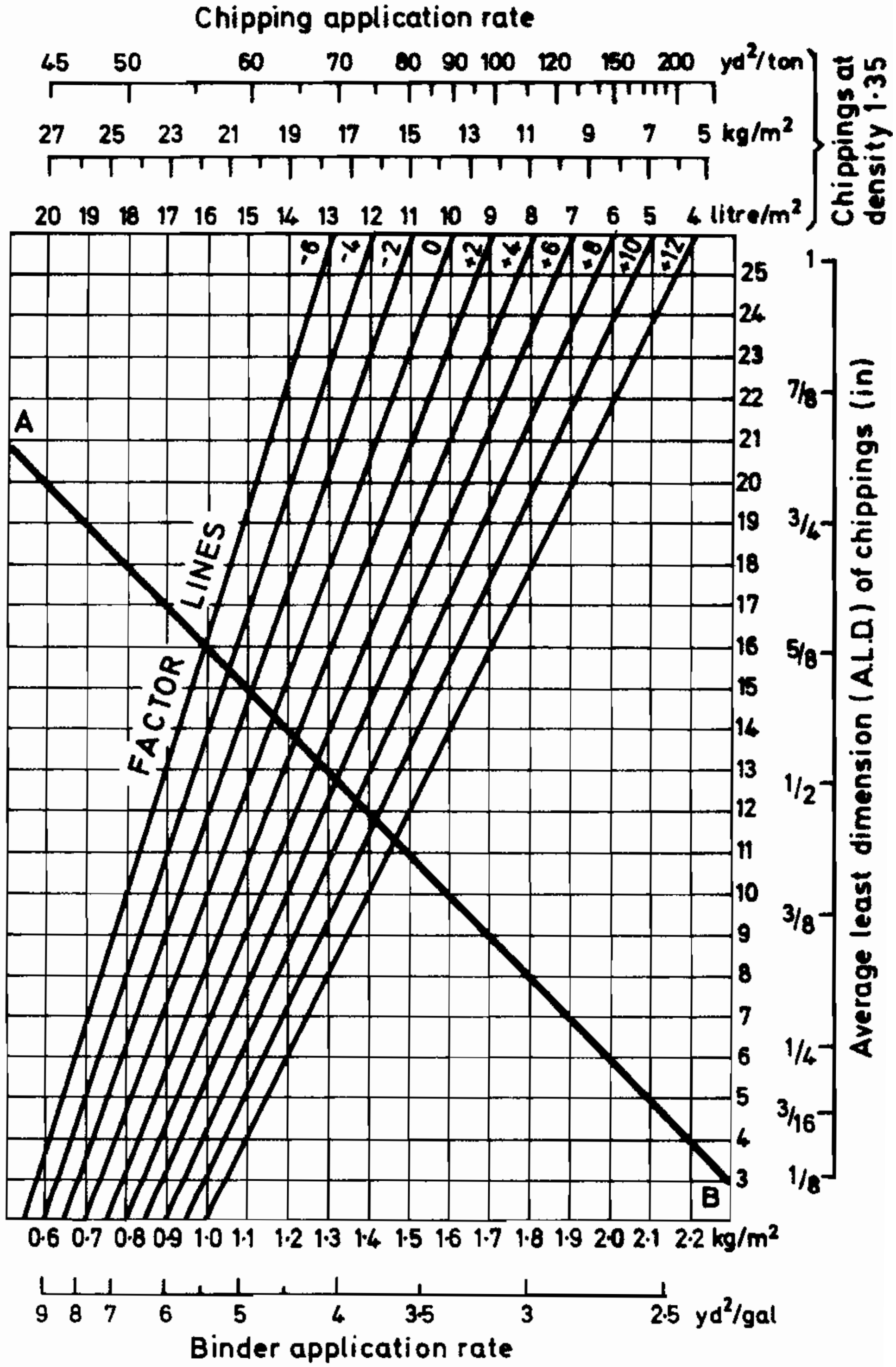


If it is desired to provide at the time of construction a pavement capable of carrying more than 0·5 million standard axles the designer may choose either a 150 mm (6in) base with a 50mm (2in) bituminous surfacing or a 200mm (8in) base with a double surface dressing. For both of these alternatives, the recommended sub-base thickness is indicated by the broken line.

Alternatively, a base 150 mm (6in) thick with 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 (2 in) of bituminous surfacing or at least 75mm (3in) of crushed stone with double surface dressing. The largest aggregate size in the crushed stone must not exceed 19 mm (¾ in) 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.

Appendix 1 PAVEMENT DESIGN CHART FOR FLEXIBLE PAVEMENTS



Appendix 2 SURFACE DRESSING DESIGN CHART

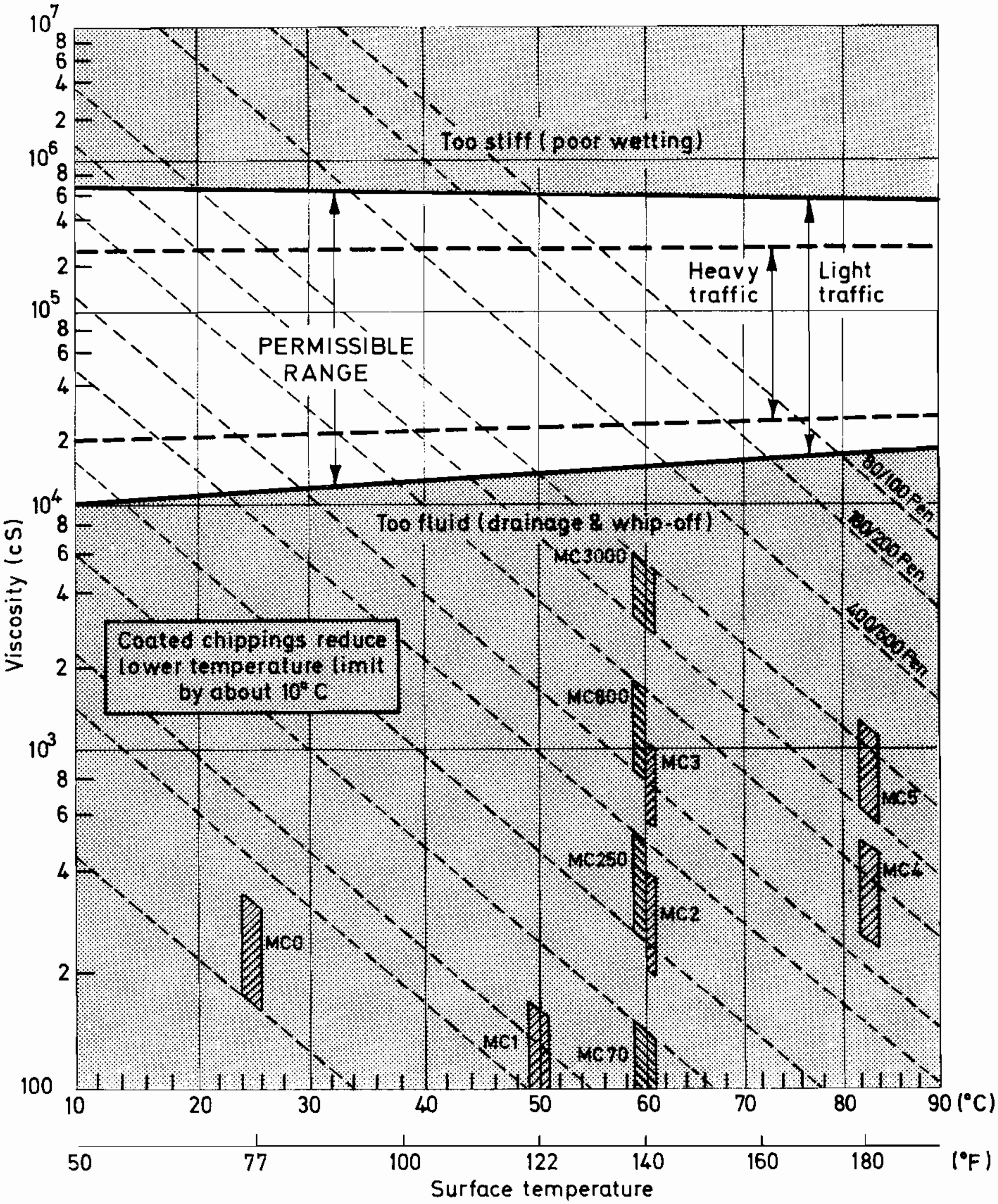
Required mean summer SFC at 50 km/h	PSV of aggregate necessary					
	Traffic in commercial vehicles per lane per day					
	250 or under	1000	1750	2500	3250	4000
0·30	30	35	40	45	50	55
0·35	35	40	45	50	55	60
0·40	40	45	50	55	60	65
0·45	45	50	55	60	65	70
0·50	50	55	60	65	70	75
0·55	55	60	65	70	75	
0·60	60	65	70	75		
0·65	65	70	75			
0·70	70	75				
0·75	75					
Aggregate (9) abrasion value	not greater than 12			not greater than 10		

SFC = sideway force coefficient (31)

(hatched) 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

Appendix 3

PSV OF AGGREGATE NECESSARY TO ACHIEVE THE REQUIRED SKIDDING RESISTANCE IN BITUMINOUS SURFACINGS UNDER DIFFERENT TRAFFIC CONDITIONS



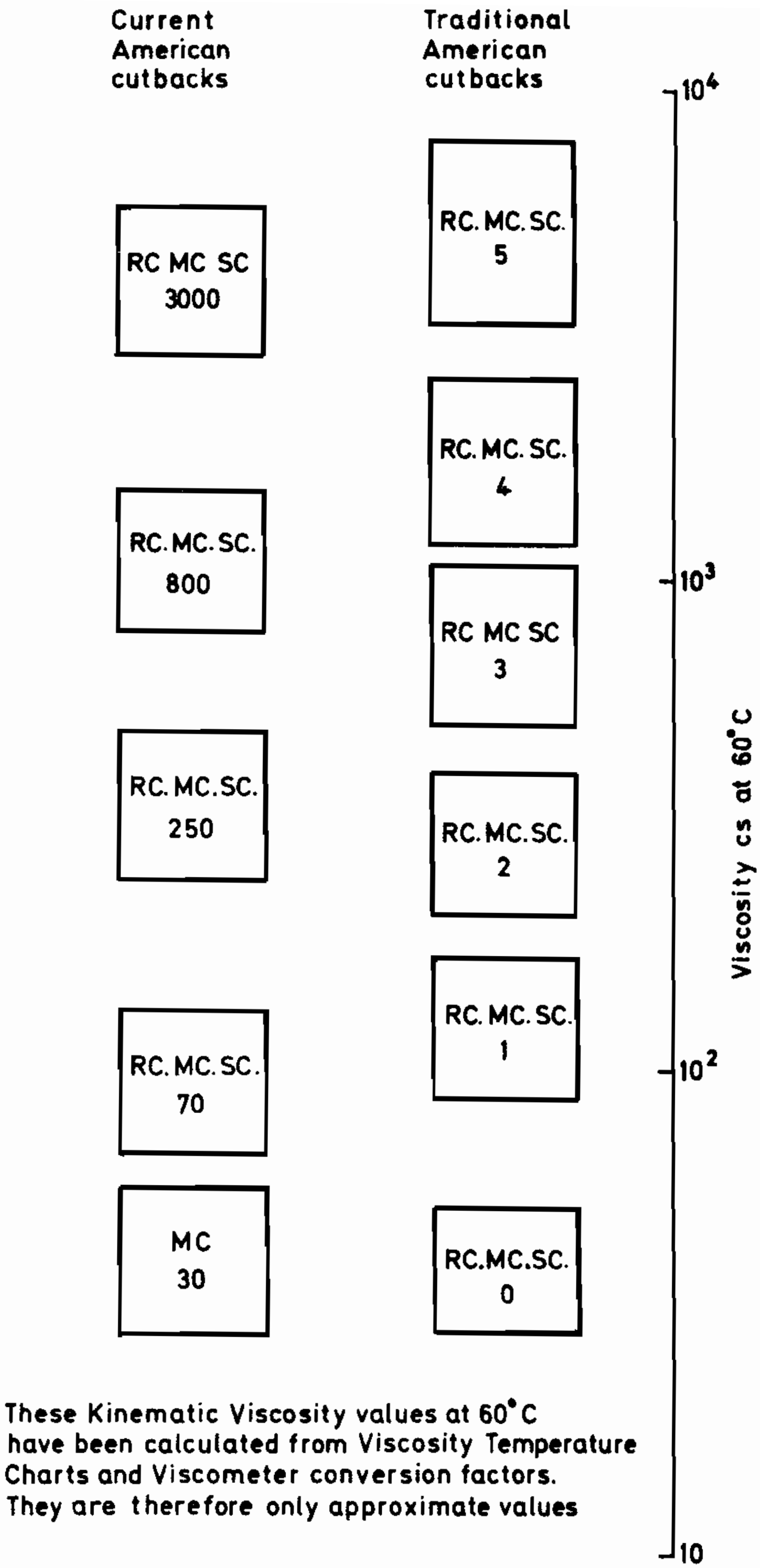
Appendix 4 SURFACE TEMPERATURE/CHOICE OF BINDER FOR SURFACE DRESSING

APPENDIX 5: Suggested Marshall design criteria for road surfacings in the tropics

raffic level	Tyre Pressure(P) range (psi)	Stiffness, S/F* = 1.2P	Range of flow values (in x 10-2)	Calculated Stability range-(lb)	Suggested range of Marshall stability & flow values				S/F Range		
					lb	$in x 10^{-2}$	kg	mm	$\frac{lb}{in x 10^{-2}}$ ≠	$\frac{kg}{mm}$ ≠	$\frac{kN}{mm}$
ight	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
edium	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
eavy	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



Appendix 6 AMERICAN CUTBACK GRADES

APPENDIX 7 - 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 conditions of the equipment affects the optimum spraying temperature.