U.K. Design Procedure for Surface Dressing

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In the United Kingdom, a design guide for surface dressings (also known as chip seals) has been developed and is now in its third edition. The input parameters can be categorized as follows: (*a*) traffic category; (*b*) hardness and condition of the existing road surface; (*c*) location and geometry of the site; (*d*) site requirements for skid resistance; and (*e*) seasonal and weather factors. Detailed consideration is given to the chippings and the binders that lead to the selection of a particular process for a particular application. Attention is paid to the planning of the work and to the requirements for aftercare. A computer program has been developed to assist the designer in the task, ensuring that all aspects are considered.

Surface dressing is the principal method of routinely maintaining road surfaces in the United Kingdom.

DEFINITION

Surface dressing, also known as chip seal, is used on all types of roads, from unclassified to motorways, and is suitable for both concrete and bituminous roads. The concept is simple: a thin layer of bituminous binder is applied to the road surface on which stone chippings are spread and then rolled.

The maintenance treatment is designed to provide an adequate skidding resistance, retard deterioration in the road surface, and waterproof the road. Additional reasons for applying a dressing are to provide a distinctive color and to provide a uniform appearance. It does not strengthen the structure of the road, improve the longitudinal or transverse profile, or improve riding quality.

TYPES OF DRESSING

There are several surface dressing systems that vary according to the number of layers of chippings and binder. The main types (excluding the resin-based high skid-resistant systems) are as follows:

- *Single surface dressing*. One application of binder followed by one layer of chippings. This system has the least number of operations, uses the least amount of material, and is sufficiently robust for many situations. Nevertheless, there is a limit to the stresses that this system can withstand.
- *Pad coat*. A single dressing using small chippings is applied to a road that has uneven surface hardness, possibly due to extensive patching or to flushing. The pad coat produces a more uniform surfacing which can be subsequently surface dressed.
- *Racked-in surface dressing*. One application of binder, one layer of chippings at about 90 percent of what would be used in a single dressing system followed by a second layer of smaller chippings. The smaller chippings lock the larger chippings in position, producing a stable matrix. The system is used where traffic is particularly heavy and fast and where the stresses are high.
- *Double dressing*. As for the racked-in system but with a second application of binder between the layers of chippings. The system usually produces a lower texture depth than a racked-in system using the same size chippings and is suitable for road surfaces which are "lean." Generally used in high-stress locations.
- *Sandwich dressing*. A layer of chippings only is applied before a single dressing. The system is used in situations in which the road surface condition is binder rich, usually just in the wheel-paths.

These types of surfacing dressing are shown in Figure 1.

DESIGN METHOD

The need for methods to design surface dressings is demonstrated by the failures that occur all too frequently, resulting in the poor reputation of surface dressing in some areas. In the United Kingdom, the design of surface dressings is generally carried out to the third edition of *Road Note 39* (*1*). The basic principal of *Road Note 39* is to choose the type of system depending on a number of factors reflecting the condition of the site and the traffic stresses exerted on the surface layer. The aggregate size is selected depending on the expected longer-term embedment, which is an equilibrium between the intensity of the traffic and the hardness of the existing surfacing. Finally, the amount of binder is selected to hold the chippings in place but minimizing the possibility of it fatting-up.

The third edition of *Road Note 39, Design Guide for Road Surface Dressing* (*1*), together with the Road Surface Dressing Association's *Code of Practice for Surface Dressing* (*2*), provide a complete guide to the practice of surface dressing and its specification as practiced in the United Kingdom. This information is based on systematic experiments and trials carried out by the Transport Research Laboratory (TRL) over many years, in close cooperation with both the idustry and highway authorities. The main features of this practice are outlined below.

DESIGN PRINCIPLES FOR SURFACE DRESSING

The decisions to be made when specifying surface dressing for a particular length of road are outlined in the flow chart in Figure 2. They apply to schemes in general and are particularly relevant to

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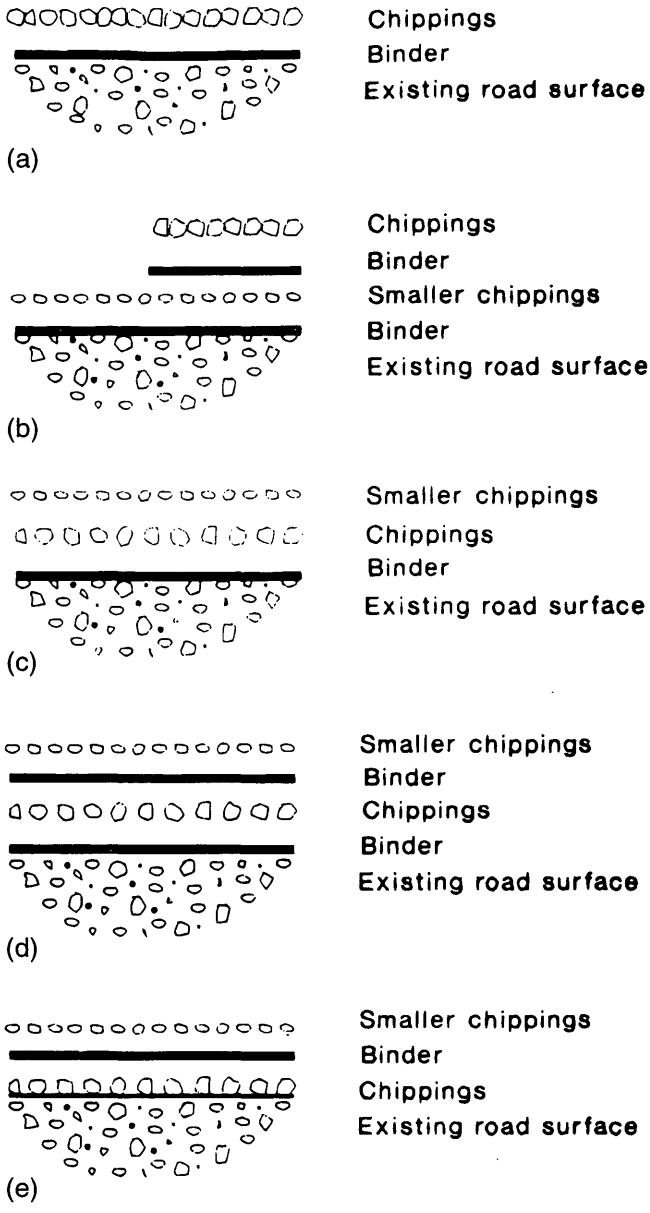

FIGURE 1 Types of surface dressing: (*a*) single dressing, (*b*) pad coat plus single dressing, (*c*) racked-in dressing, (*d*) double dressing, (*e*) sandwich dressing.

high-speed roads carrying heavy traffic. Experience suggests that if the recommendations are followed, surface dressing treatments are cost-effective.

INPUT PARAMETERS

Traffic Categories

A major factor in designing a surface dressing is the anticipated volume of traffic the road is required to carry. Commercial vehicles cause most of the embedment of chippings and, for design purposes, the current number of commercial vehicles per lane per day is used to represent the traffic flow. In this context, a commercial vehicle is defined as a vehicle of unladen weight greater than 1.5 T (Mg). The full classification system is given in Figure 3.

Road Hardness

Measurements are made on a representative length of the nearside wheel track in each lane using a probe. The probe, 4 mm in diameter of hardened steel and machined to a hemispherically shaped tip, is attached to an instrument capable of applying a constant load of 35 kg/ft (343 N) to it. The surface temperature, which should preferably be between 15 and 35°C, for each set of 10 penetration readings is recorded and the hardness category evaluated from Figure 4.

The measurements should normally be made in the season before that in which the surface dressing is to be carried out. As an alternative to in situ assessment, if 150-mm-diameter cores have been extracted from the road for some other purpose, these can be tested for hardness in the laboratory.

Road surfaces are divided into five categories, as given in Table 1. Concrete road surfaces present extreme resistance to embedment of chippings under the action of traffic and are classified as very hard. At the other extreme, patched areas of bituminous surfacings are usually the softest materials. If there is considerable variability in hardness along the length of the site, then this should be taken into account.

Surface Condition

The condition of the existing surfacing is important in determining the most appropriate type of surface dressing. It is important that sufficient binder is present for the initial retention of the chippings until embedment takes place in the longer term. Therefore, the more binder-rich the surface, the less binder required to retain the chippings. The surface condition can be divided into five categories:

1. Very binder rich,
2. Binder-rich;
3. Normal,
4. Porous, and
5. Very porous and binder-lean.

Allocation to a particular category is a subjective assessment that should be carried out by an experienced person.

Location and Geometry of Site

Roads seldom can be considered as uniform along their length. Not only can the factors described above change along the length of the site, but also the geometry of the road is almost certain to vary on any but the shortest of sites. Therefore, the following parameters must be allowed for as they change along the length of the road: radius of curvature, gradient, altitude, and shade. These factors are taken into account in the *Design Guide for Road Surface Dressing* (*1*).

Site Requirements for Skid Resistance

The skid resistance of the highway network is monitored by the Sideway-force Coefficient Routine Investigation Machine

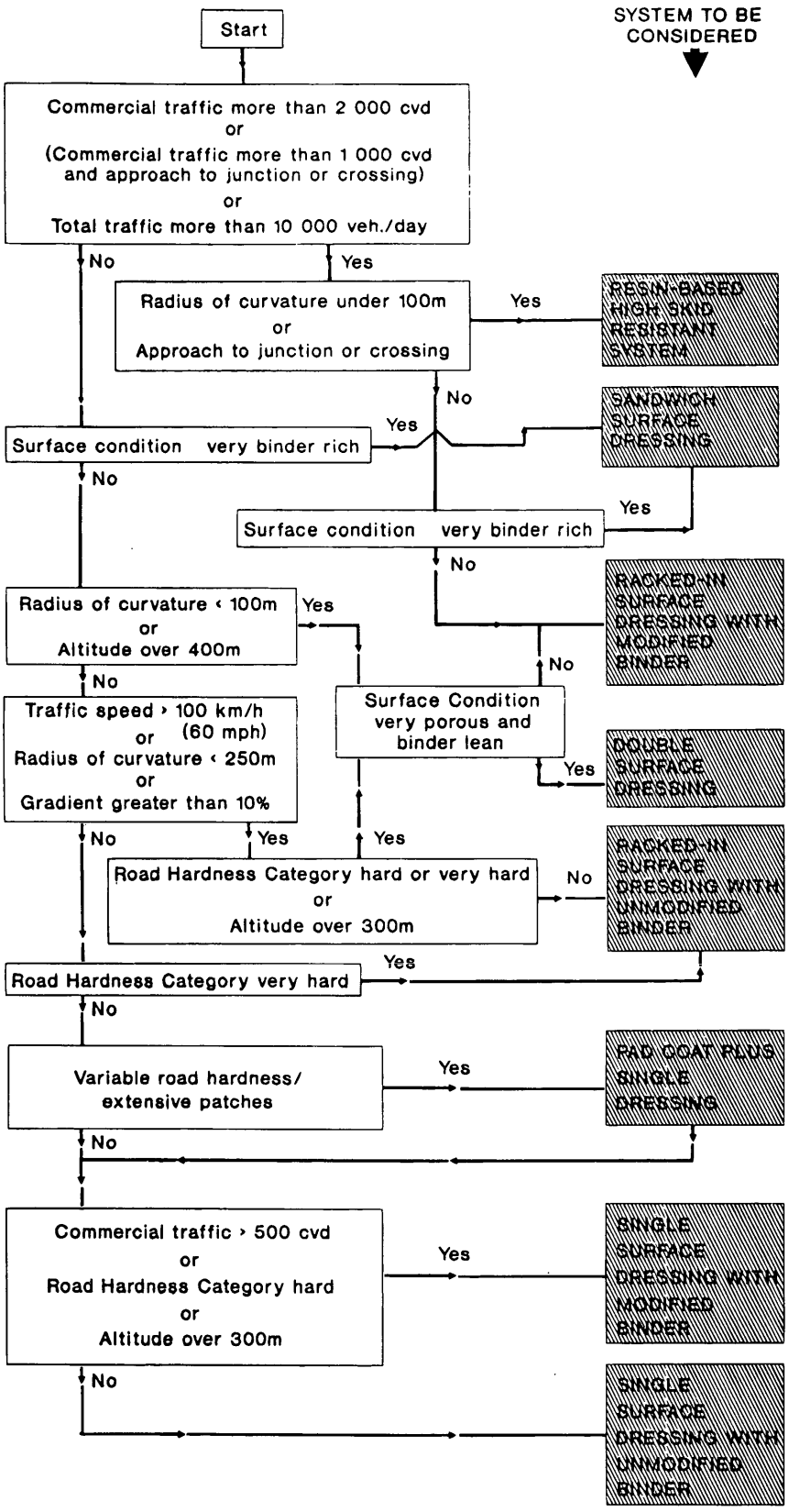

FIGURE 2 Flow diagram for planning and specification of surface dressing.

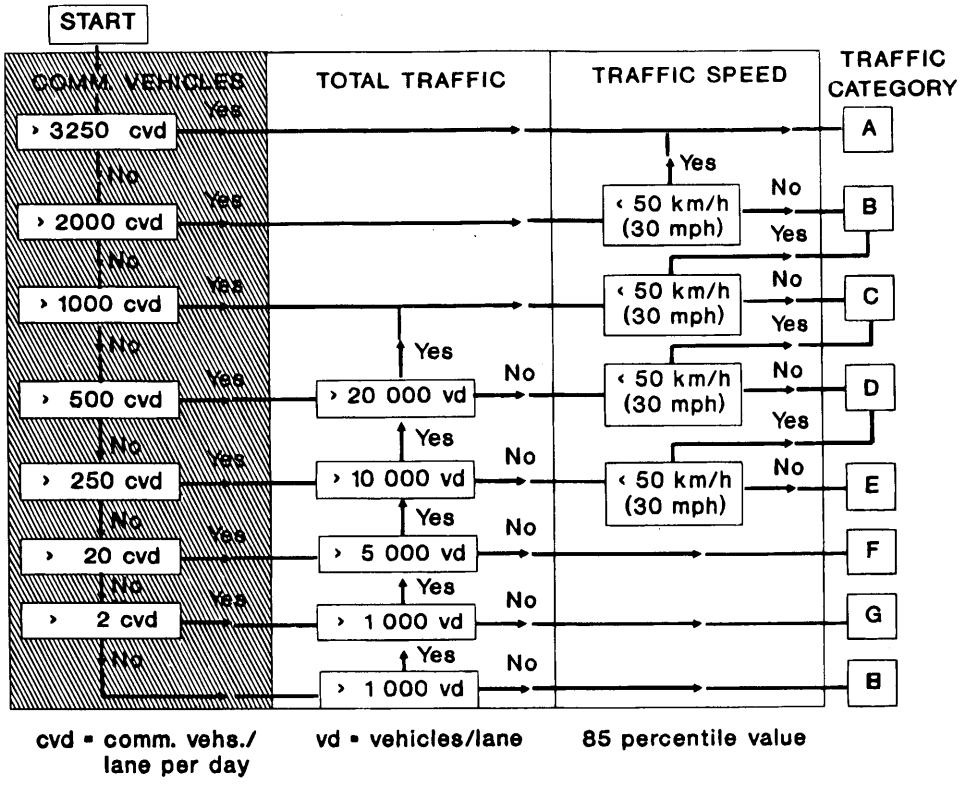

FIGURE 3 Traffic categories.

(SCRIM), and the levels found are related to those for motorways and trunk roads in the United Kingdom, as laid down in the *Design Manual for Roads and Bridges, Vol. 7: Pavement Design and Maintenance* (*3*); the advice for non-trunk roads is given in *Highway Maintenance—A Code of Good Practice* (*4*).

Surface dressing is one of the most cost-effective ways of rehabilitating the skid resistance of the surfacing. The aggregate can be selected to have suitable polish-resistant properties. The polished-stone value (PSV) of the aggregate in the road surface and the commercial vehicle traffic have been found to correlate with the skid

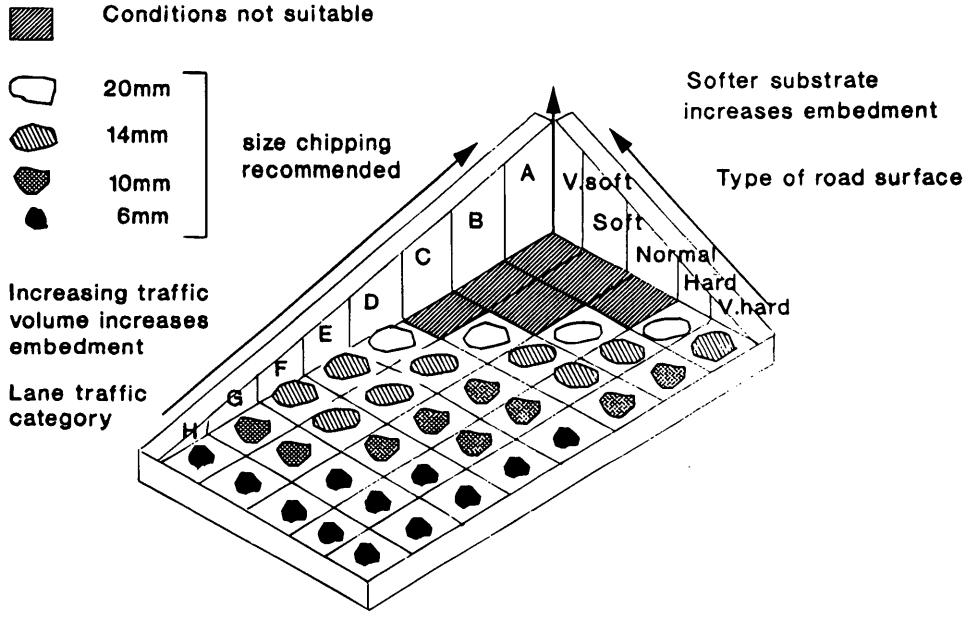

FIGURE 4 Hardness categories from depth of penetration and road surface temperature.

TABLE 1 Road Surface Hardness Categories

Hardness	Description of surface
Very Hard	Surfaces such as concrete or exceptionally lean bituminous mixtures with dry stony surfaces into which there will be negligible penetration of chippings under heavy traffic loads.
Hard	Surfaces containing some hard bituminous mortar into which chippings will penetrate only slightly under heavy traffic.
Normal	Surfaces into which chippings will penetrate moderately under heavy and medium traffic.
Soft	Surfaces into which chippings will penetrate considerably under heavy and medium traffic.
Very Soft	Surfaces into which even the largest chipping will be submerged under heavy traffic. Such surfaces are usually rich in binder.

resistance of the road. The relationship between skid resistance, traffic, and the required PSV of the aggregate is such that the *Design Manual for Roads and Bridges, Vol. 7: Pavement Design and Maintenance* lays down the required minimum PSV of chippings for new and replacement works. Table 2 reproduces the basic requirements.

Seasons and Likely Weather Conditions

Surface dressing is a seasonal activity. This is not only because of the difficulties of surface dressing in cold weather, but primarily because the long-term stability of the treatment is dependent on the chippings becoming embedded before the onset of cold weather. In

TABLE 2 Minimum PSV Requirements for Aggregates

Site Definition	Traffic	Min. PSV
Motorway	less than 1750	55
	1751 - 2250	57
Dual carriageway	2251 - 2750	60
(non-event sections & minor junctions)	2751 - 3250	65
	over 3250	68
Single carriageway	less than 100	45
(non-event section & minor junctions)	100 - 250	50
	251 - 750	53
	751 - 1000	55
	1001 - 1500	57
	1501 - 1750	60
	1751 - 2250	63
	2251 - 2750	65
	over 2750	68
Major junction approaches (all limbs)	less than 100	50
	100 - 250	55
Gradient 5% to 10% longer than 50 m,	251 - 500	57
dual downhill; single uphill and downhill	501 - 1000	60
	1001 - 1500	63
Bend (no speed limit), radius 100 m - 250 m	1501 - 2000	65
	2001 - 2500	68
Roundabout	over 2500	70+
Gradient over 10% longer than 50 m,	less than 100	55
dual downhill; single uphill and downhill	100 - 250	60
	251 - 750	63
Bend (no speed limit) < 100 m	751 - 1250	65
	1251 - 1750	68
	1751 - 2500	70+
Approaches to roundabouts, traffic signals,	less than 100	63
pedestrian crossings, etc	100 - 250	65
	251 - 1000	68
	1001 - 2500	70+

the design of surface dressings it is assumed that the chippings will be embedded into all but the hardest road surface. If embedment does not occur, some of the chippings are liable to be removed by traffic during the first winter. Use of modified binders may reduce the susceptibility of a surface dressing to such failures. In the United Kingdom, different binders have been recommended for the different traffic categories for use in the various seasons of the year.

The seasons quoted are only a guide because the weather in any year may differ from the mean in the United Kingdom. Therefore, the periods may be reduced or expanded to suit long-term weather forecasts and local situations.

MATERIALS

Chippings

The standard single-sized chippings used in the United Kingdom are 20, 14, 10, 6, and 3 mm, although the 20-mm size is usually avoided because of the potential damage from loose chippings and the 3-mm size is used only for racking-in. All chippings should comply with the general requirements for size, shape, and strength included in BS 63: Part 2 (*5*). Low levels of "dust" are specified and some surface dressing aggregates are prewashed. Samples of chippings should be tested for compliance before the start of work and subsequently as more deliveries are received.

The size of chippings should be chosen to suit the traffic and the hardness of the substrate, as given in Figure 5. The sizes of chipping specified are related to the midpoint of each traffic category: for lighter traffic conditions, the next smaller size may be more appropriate. Dressings with larger-size chippings should be carried out early in the season in order to ensure adequate embedment before the onset of cold weather.

The quantity of chippings applied must be sufficient to cover the binder film. The chippings should be spread at a rate to achieve 100–105 percent shoulder-to-shoulder coverage as determined by BS 598: Part 108 (*6*). The quantity required will depend on the size, shape, and relative density of the chippings selected. The actual rate of spread of chippings can be measured by means of a tray test described in Appendix F of *Road Note 39* (*1*). Excess chippings left on the surface should be removed before the site is opened to free-flowing traffic.

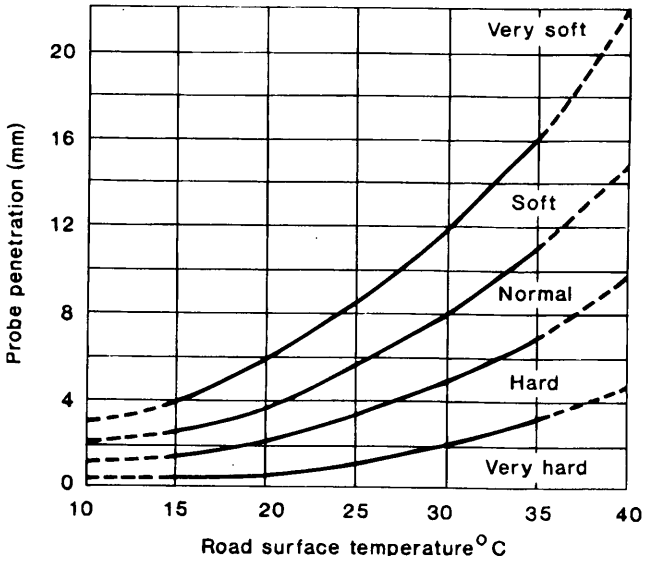

FIGURE 5 Use of different size chippings in single surface dressings.

Binders

The unmodified binders available for surface dressing work in the United Kingdom are as follows:

- Bitumen emulsion to BS 434: Part 1 (*7*), Table 2; and
- Cut-back bitumen to BS 3690: Part 1 (*8*), Table 2.

Surface dressing binders are classified in terms of their viscosity. Different measures of viscosity are used for the different types of binder, as follows (in which STV is standard tar viscometer):

- Seconds Redwood II at 85°C for hot emulsion;
- STV seconds at 40°C for cut-back bitumen; and
- Penetration at 25°C for residual bitumen.

Proprietary modified binders, made by addition of polymers or other means, are available. There is no standard specification for these binders at present, but a suite of discriminatory tests is under development, which may include such tests as mini-fretting, toughness and tenacity, Vialit, and rheological characteristics. Compliance requirements have to be based on one or more provisional test methods, or a performance criterion, or local experience on previous jobs.

The addition of polymers to bituminous binders modifies the performance in a number of ways depending on the polymer used. Typically, improved performance in one or more of the following areas is possible:

- Reduced temperature susceptibility in service;
- Improved low temperature adhesion and elasticity;
- Improved elasticity to bridge hairline cracks in the underlying surface;
- Improved early "grip" on the aggregate;
- Improved long-term cohesion of the system;
- Improved durability as thicker films are possible; and
- Earlier release of the site to free-flowing traffic.

Recommendations for classes and viscosity grades suitable for surface dressing carried out in the United Kingdom have been developed and are given in Table 3. Bitumen emulsions are defined by class instead of viscosity grade. Generally, 70 percent binder content classes are recommended. The recommended viscosities are based on seasonal norms in the United Kingdom. In using Table 3, consideration should be given to any exceptional weather conditions that may occur, and to differences in climate between northern and southern regions of the United Kingdom. Traffic categories *A*, *B*, and *C* are considered as special cases. For traffic categories *A* and *B*, modified bitumen emulsion or cut-back bitumen is preferred, although unmodified cut-back bitumen can be used in certain circumstances. For traffic category *C*, K1-70 bitumen emulsion (in which K1-70 is a cationic emulsion with 70 percent bitumen content) may also be used.

TABLE 3 Classes and Viscosity Grades for Unmodified Binders

ROAD TRAFFIC CATEGORY	PERIOD OF YEAR	BITUMEN EMULSIONS	CUT-BACK BITUMEN
A	-	-	-
B & C	May to mid-July	K1-70*	200 sec*
D - H	April, May & Sept	K1-70	50 or 100 sec
D - H	June to August	K1-70	100 or 200 sec

* Modified binders preferred for road traffic categories A, B and C

High-viscosity binders should be used on roads of traffic category *D* to *H* in which the 85th-percentile traffic speed exceeds 100 km/hr (60 mph) in order to resist displacement of chippings by high-speed traffic. Emulsions with base binders of suitable viscosity or 200 sec grade cut-back bitumens are appropriate. The use of lightly coated chippings is recommended if high-viscosity cut-back binders are used.

Specification requirements have been developed for epoxy-resin modified binder. The binder is a two component, chemical-set system comprising a resin component and a bituminous component containing the hardener. These two components are kept separate until the time of spraying, and are proportioned according to the manufacturer's recommendations. These recommendations should be followed, and the cured binder should comply with the specification given in BS 2782: Part 3, method 320A (*9*).

Proprietary thermoplastic polymerized resin-ester and acrylic-resin binders as well as thermosetting polyurethane-resin binders have become available as alternatives to epoxy-resin. The thermoplastic resin-ester binder is based on highly stabilized resin acids polymerized with ethylene/vinyl acetate co-polymers. The relative advantages of the thermoplastic binders over epoxy-resin are that they are not two-part systems and do not require a minimum temperature to effect a cure. The polyurethane-resin binder is a three component system applied in similar way to epoxy-resin systems. The durability of these systems is still being assessed.

DESIGN PROCEDURE

Selection of Type of Dressing

The types of surface dressing available are shown in Figure 1. The choice of an appropriate surface dressing system depends on a number of factors. Figure 6 gives a simplified flow diagram to aid selection. In boxes with several alternative criteria, the "No" branch is used if none of them is met, whereas the "Yes" branch is followed if even one of those criteria is met. The sets of criteria are arranged so that the harshest conditions dictate the system to be used, minimizing the risk of failure. The return arrow from the "pad coat plus single dressing" selection is used to identify whether the binder for the single dressing should be modified or unmodified.

The system selected by following Figure 6 is not necessarily the only one that can be used in the circumstances; this figure simply identifies one system that is suitable for consideration. Also, there may be reasons other than those included in the decision tree for using a different system from that arrived at from this figure. The system indicated may be regarded as either over- or underdesign, in which cases consideration should be given to a less or more expensive option, respectively. Possible reasons could include when the road has a limited structural life, when the traffic intensity is expected to change in the foreseeable future, or when the road has a strategic importance for reasons other than traffic flow. All such considerations should be taken into account when choosing the most appropriate system.

Rate of Spread of Binder

The rate and uniformity of spread of binder are two of the most important factors affecting the quality of a surface dressing. The equipment should be calibrated for the particular binder being used and the rate should always be checked during the early stages of the work. The uniformity of spread should be measured using the carpet-tile test in BS 1707 (*10*); the average rate of spread can be obtained by dipping the tank and measuring the area.

The required rate of spread depends on the size and shape of the chippings, the nature of the existing road surface and the degree of embedment of chippings by traffic. *Road Note 39* (*1*) gives general guidance on rates of spread together with recommended chipping sizes for the various types of surface and traffic categories. The rate of spread of binder at spraying temperature should not vary by more than ± 10 percent of the target figure, either longitudinally or transversely.

Example of Design

For a single carriageway, two-lane road along a non-event but partially shaded section at an altitude of 100 m which carries 8,000 vehicles, of which 450 are commercial, per lane per day at an 85th-percentile speed of 80 km/hr with an existing surfacing that is categorized as having normal road hardness and surface condition, the type of dressing selected using Figure 6 will be single surface dressing with modified binder. The traffic category from Figure 3 will be *E*.

Figure 5 proposes the use of 10-mm chippings. If K1-70 bitumen emulsion is to be used as the binder, a table in *Road Note 39* (*1*) gives the binder quantity as 1.5 L/m^2 with an adjustment of +0.1 L/m^2 for being shaded. Therefore, the design is a single surface dressing with 10-mm uncoated chippings and 1.6 L/m^2 K1-70 bitumen emulsion.

Final Specification and Costing

Having designed the surface dressing system (or systems) required, an engineer should be able to prepare a specification for the work.

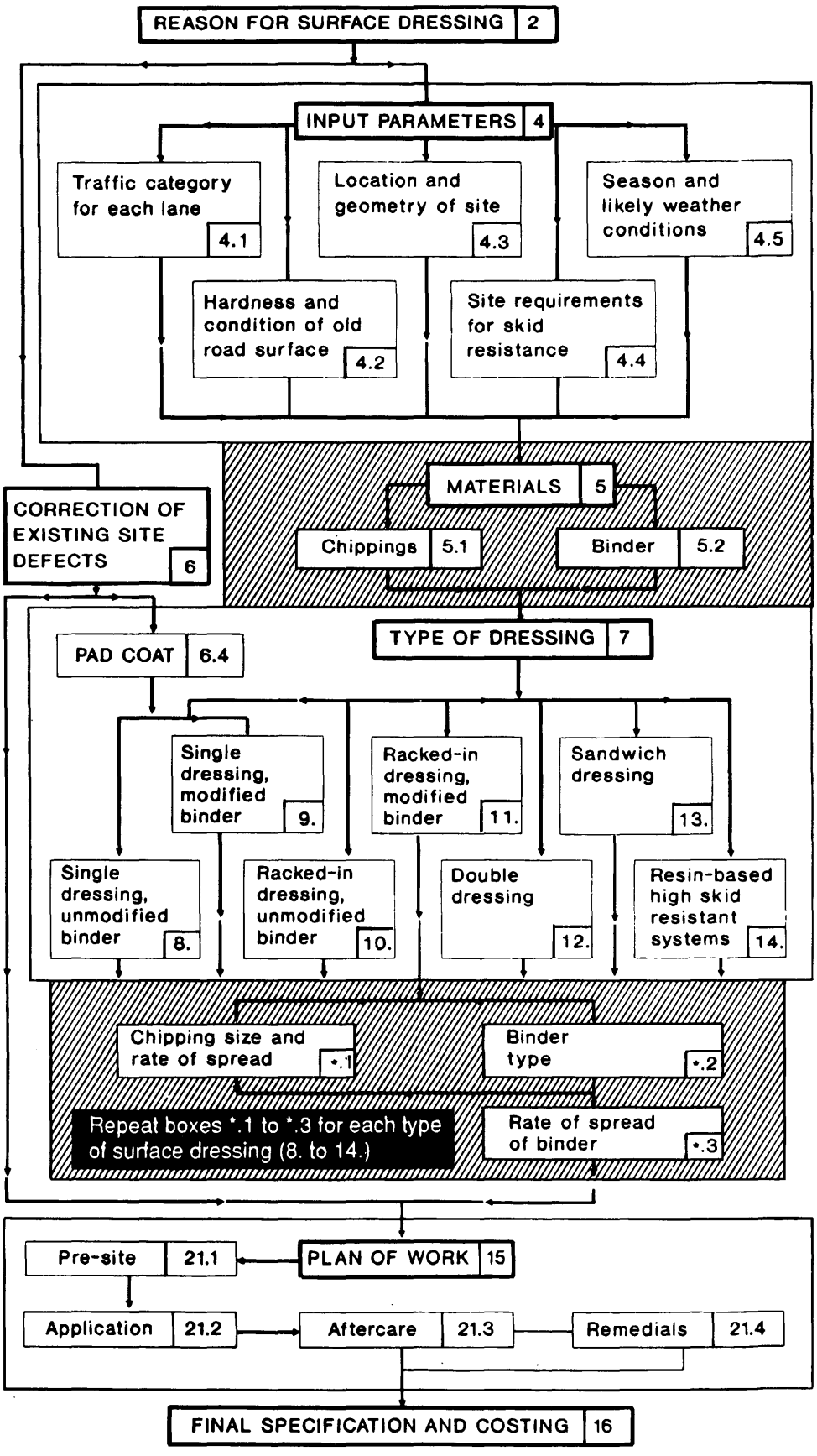

FIGURE 6 Selection of type of surface dressing.

An estimate of the cost of the scheme can be derived from knowledge of the system to be used and calculations of the quantities of materials required, based on the rates of spread and the area to be covered.

Records of past surface dressing work, considered in the light of the subsequent performance, should be used as the basis of specifications for future work. Therefore there are obvious advantages, to both clients and contractors, in keeping accurate and detailed records of the significant factors in surface dressing work. Such factors include the following:

- Traffic conditions;
- Nature and area of the road surface;
- Weather conditions during and immediately after the work;
- Type, grading, condition, and rate of spread of chippings and the method of applying them;
- Type, viscosity, and rate of spread of the binder and the method of applying it; and
- The type and amount of rolling employed.

Correction of Existing Site Defects

Before any surface dressing the existing road surface needs to be examined for defects. This investigation should be carried out in the previous season and remedial works completed in advance. The procedures differ according to whether the surface is bituminous or cement bound.

COMPUTER PROGRAM

Each operation in the design process is very simple, but the number of them can make it appear more complex. To simplify the process for those who do not design frequently and to provide a record of each design carried out for those who do, TRL now markets a small computer program which can carry out the work. However, because there is no unique "correct" design for each situation, alternatives are allowed for in the program.

The program allows for the designer to change certain parameters from those selected by strict adherence to the rules in *Road Note 39* (*1*). This is because it is appreciated that engineering judgment does have a part to play in the design process, if only to avoid having to change the type of surface dressing and size of chippings for every lane and every time some other parameter value may change: even if the design is marginally more "correct," each change increases the chance of error.

The program, as for *Road Note 39* itself, is derived from experience in the United Kingdom. Although the general approach should be applicable to the design of surface dressings anywhere, the parameter values may need to be changed for reasons of different climate, different materials, and/or different construction practices used in other countries.

USE ON HEAVILY TRAFFICKED ROADS

Road trials using this design approach have been carried out to validate the use of surface dressing on heavily trafficked roads; these trials included sites located on the A34 at Chieveley, Berkshire, the A55 at Chester, the M2 in Kent, the A449 at Kidderminster and various locations in Scotland (*11*). The trial sites at both Chieveley and Chester indicate that, for relatively straight, heavily trafficked roads where the traffic stresses are relatively low, the difference in performance of the various types of binder is not great. In fact, provided that every precaution is taken during the laying and initial aftercare of the dressing, unmodified binders can be successfully used at these types of site. The trials also indicated that there was little difference in performance between modified emulsions and modified hot-applied binders where they had been used under similar conditions. The conclusions from the trials in Scotland were that on relatively straight length road sites, all the proprietary binders performed adequately, with no system being significantly better than another.

The improvements in surface dressing binders and techniques have led to a greater confidence in using surface dressing as a maintenance option for the arterial road network. Many trunk roads have been successfully surface dressed which, in turn, has led to surface dressing contracts being carried out on parts of the heavily trafficked motorway system. Surfacing dressing has been used on motorways under normal contract conditions on the M1 in Northern Ireland, the M25 in Kent and the M1 in Northamptonshire. These have indicated that surface dressing can be successfully used on the most heavily trafficked roads in the United Kingdom, provided the most suitable technique is specified and the work is carried out in late spring to mid-summer. The use of modified binders with the specified system appears to reduce the risk of early failure. It is essential that a comprehensive plan for the work is drawn up, together with contingency plans for adverse weather and remedial measures.

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