

# A proposed new design method for bituminous surface treatments

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## ABSTRACT

*Bituminous Surface Treatment (BST) is single or double application of binder and chipping on prepared granular base or existing chipping layer or old asphalt concrete for preventive purposes. In Turkey, BST is widely preferred because of relatively lower cost and faster construction than those of conventional asphalt concrete. There are a few BST design method in the world and all are basically derived from first design method proposed by Hanson.*

*UK design method has been used for about 50 years in Turkey. The long years experiences of BST applications has been revealed the need for new design method since the existing design values significantly need to be modified in the field. This paper proposes a new design method, namely "KGM Design Method", for single and double surface treatments considering laying season as well as Average Least Dimension of Aggregate, climate, surface characteristics, aggregate and binder properties.*

**Keywords:** Chip seals, Design of pavement, Interlayer (SAMI), Surface dressing

## 1. INTRODUCTION

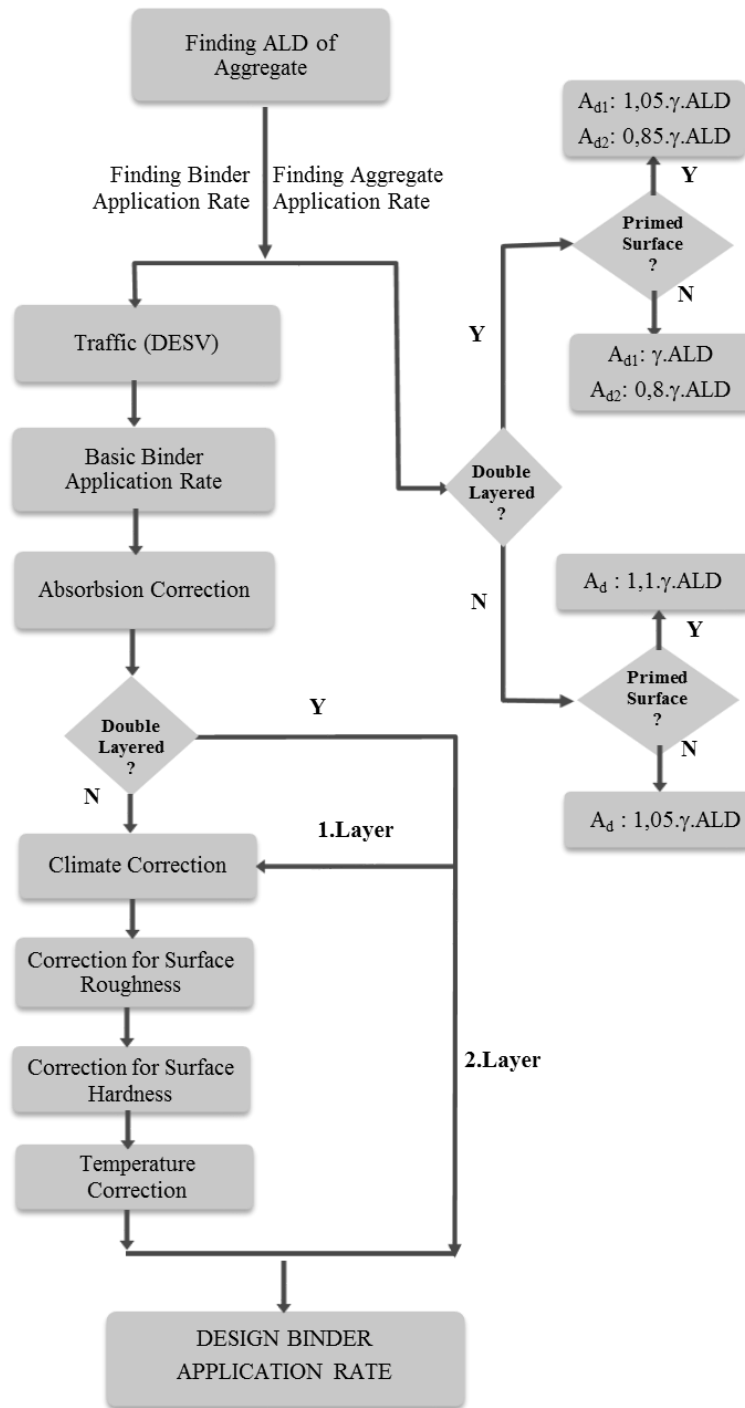
Surface treatments formed by spreading the bituminous binder and aggregate material on the prepared road surface one after the other and compacting has been the most widely used type of pavement in Turkey for reasons such as economy and production rate.

Considering development of surface treatment design methods in the world, it is seen that the first design method was developed by Hanson in 1934 in New Zealand. Then, Kearby method developed in 1953 and modified in the later years was especially used in Texas, USA. United Kingdom (1963), McLeod (1969), New Zealand (2005) and South Africa methods based on Hanson method have been developed in the later years. These methods are essentially based on first Hanson method that has the concept that aggregate in a chip seal should be as one-sized as possible and that embedment of the aggregate in the asphalt binder should occupy a specific percentage of the aggregate dimension. How the aggregate dimension is determined and how the volume of asphalt binder is calculated vary between methods but usually require measuring the gradation of the aggregate in order to obtain the average least dimension (ALD) and the shape of the aggregate is considered important and is measured using the Flakiness Index. The percent embedment is varied as a function of traffic for methods [13]. Hanson found that for a surface treatment that has carried considerable traffic, the cover aggregate reaches its densest condition with about 20% voids. If enough asphalt binder has been applied to more than fill this 20 per cent of void spaces, the excess binder accumulates on the surface and causes flushing or bleeding. If too little binder is used, the cover stone is torn by traffic because there is not enough binder to cement the aggregate firmly into place [17]. According to this approach, raveling starts to appear if embedment falls below the rate of 30 % and exceeding 70% embedment causes bleeding.

Surface treatment design based on the United Kingdom (UK) method has been used in Turkey for many years. However, it has revealed the need to revise this method for the conditions of Turkey because of the fact that design values do not represent the amount of aggregate and bitumen to be used, new developments related to the design and the R & D activities. The proposed new design method here has been developed on the basis of design methods in the literature, practical experience in Turkey and research studies carried out up to today. The following process steps shall be followed in the new proposed design method:

1. Average Least Dimension of Aggregate (ALD) is found by using Flatness Index and Aggregate Average Dimension.
2. “Daily Equivalent Standard Vehicle Per Lane (DESV)” is calculated for the route types on which the average vehicle speed change (alignment, curves, ramps, intersections) and for each lane.
3. Basic binder application rate is determined with charts by using DESV and ALD values.
4. Design binder application rate is determined by using aggregate bitumen absorption, climate, surface texture and surface roughness corrections together with modified bitumen correction factors. It is reported with the temperature correction.
5. The amount of aggregate is determined in kg/m<sup>2</sup> depending on the type of the surface treatment layer by using ALD and bulk density values.

Flow chart related to finding the application rate of binder and aggregate in the New General Directorate Highways Design Method is shown in Figure 1.



**Figure 1: Flow chart of surface treatment design**

## 2. DETERMINATION OF THE AMOUNT OF BITUMINOUS BINDER

Procedure steps to be followed for determining the amount of bituminous binder to be applied in the new surface treatment design method are described below.

### 2.1. Determination of the Median Aggregate Size (M)

The first process in the design of surface treatment is to find the Median Aggregate Size. For this purpose, grain size distribution of the aggregate is drawn on the sieve analysis graph. In this graph, the theoretical sieve size through which the 50 % of the material passes is recorded as the Median Aggregate Size.

## 2.2. Determination of the Average Least Dimension (ALD)

The Average Least Dimension of Aggregate is one of the most important factors to determine both aggregate and binder content in surface treatment design. Aggregates tend to settle on their flat surfaces on which they have maximum stability with the impact of the traffic load after construction of surface treatment. In the position that aggregate is stable the dimension perpendicular to the surface is called the least dimension of the aggregate. The average of the least dimensions of the whole aggregate is called the Average Least Dimension (ALD).

ALD value is calculated by averaging the least dimensions perpendicular to the long edge of 100 aggregates measured with caliper or by the following equation depending on the flatness index [18].

$$ALD = \frac{M}{1,139285+0,011506 \times FI} \quad (1)$$

Where;

ALD = Average Least Dimension, mm

M = Medium Aggregate Size, mm

FI = Flatness Index, %

## 2.3. Determination of Traffic Volume

Chippings settle into surface treatment by traffic impact both embedding and aligning parallel to their longest dimension. The amount of the embedment varies depending on traffic volume, axle load and vehicle speed. In case of more than one carriageway in the same direction, while embedment is more on the right lane on which the heavy vehicle traffic is high and traffic flow speed is low, it is less on the left lane on which the fast and light vehicle traffic is high. Therefore, it is recommended to determine the effects of vehicles of different weights and speed to the surface treatment by converting into a standard 10-ton light truck vehicle and to carry out this process *for each lane separately* in the new design method.

**Table 1: Selection table for traffic factors.**

| Vehicle Type     | Vehicle Equivalency Factor (VEF) | Vehicle Speed Factor (h)     |                                     |   | Lane distribution Factor ( $\eta$ ) |           |            |           |             |            |
|------------------|----------------------------------|------------------------------|-------------------------------------|---|-------------------------------------|-----------|------------|-----------|-------------|------------|
|                  |                                  | Express Traffic <sup>1</sup> | Medium or Slow Traffic <sup>2</sup> | Very Slow or Stopped Traffic <sup>3</sup> | Lanes in One Direction              |           |            |           |             |            |
|                  |                                  |                              |                                     |   | 1                                   | 2         |            | 3         |             |            |
|                  |                                  |                              |                                     |   | Single Lane                         | Left Lane | Right Lane | Left Lane | Centre Lane | Right Lane |
| Trailer          | 6                                | 1                            | 2.0                                 | 3.0                                       | 1                                   | 0.10      | 0.90       | 0.05      | 0.15        | 0.80       |
| Truck            | 3                                | 1                            | 1.8                                 | 2.6                                       | 1                                   | 0.15      | 0.85       | 0.05      | 0.25        | 0.70       |
| Bus              | 2.5                              | 1                            | 1.6                                 | 2.2                                       | 1                                   | 0.20      | 0.80       | 0.10      | 0.40        | 0.50       |
| Pick-up, Minibus | 0.5                              | 1                            | 1.3                                 | 1.5                                       | 1                                   | 0.80      | 0.20       | 0.30      | 0.60        | 0.10       |
| Car              | 0.1                              | 1                            | 1.1                                 | 1.2                                       | 1                                   | 0.90      | 0.10       | 0.60      | 0.35        | 0.05       |

<sup>1</sup>. Average running speed > 80 km/h alignment

<sup>2</sup>. Average running speed = 40 – 80 km/h ramp descents, curbs and city crossings

<sup>3</sup>. Average running speed < 40 km/h ramp ascents, switchback curves, intersections

Daily equivalent standard vehicle traffic is calculated separately by the following equation for each lane and for each section of the different speed category.

$$DES\text{V} = \frac{AADT \times VEF \times h \times \eta}{i} \quad (2)$$

Where;

DES\text{V} = Daily Equivalent Standard Vehicle Per Lane (Equivalent Vehicle/Lane/Days)

AADT = Annual Average Daily Traffic (Vehicle/Days)

h = Vehicle Speed Factor

$\eta$  = Lane Distribution Factor

i = Number of Traffic Direction

## 2.4. Determination of the Basic Binder Application Rate

After determining average least dimension of aggregate and daily equivalent standard vehicle traffic per lane, Basic Binder Application Rate ( $B_b$ ) to be used in the surface treatment is found from the chart in Figure 2.

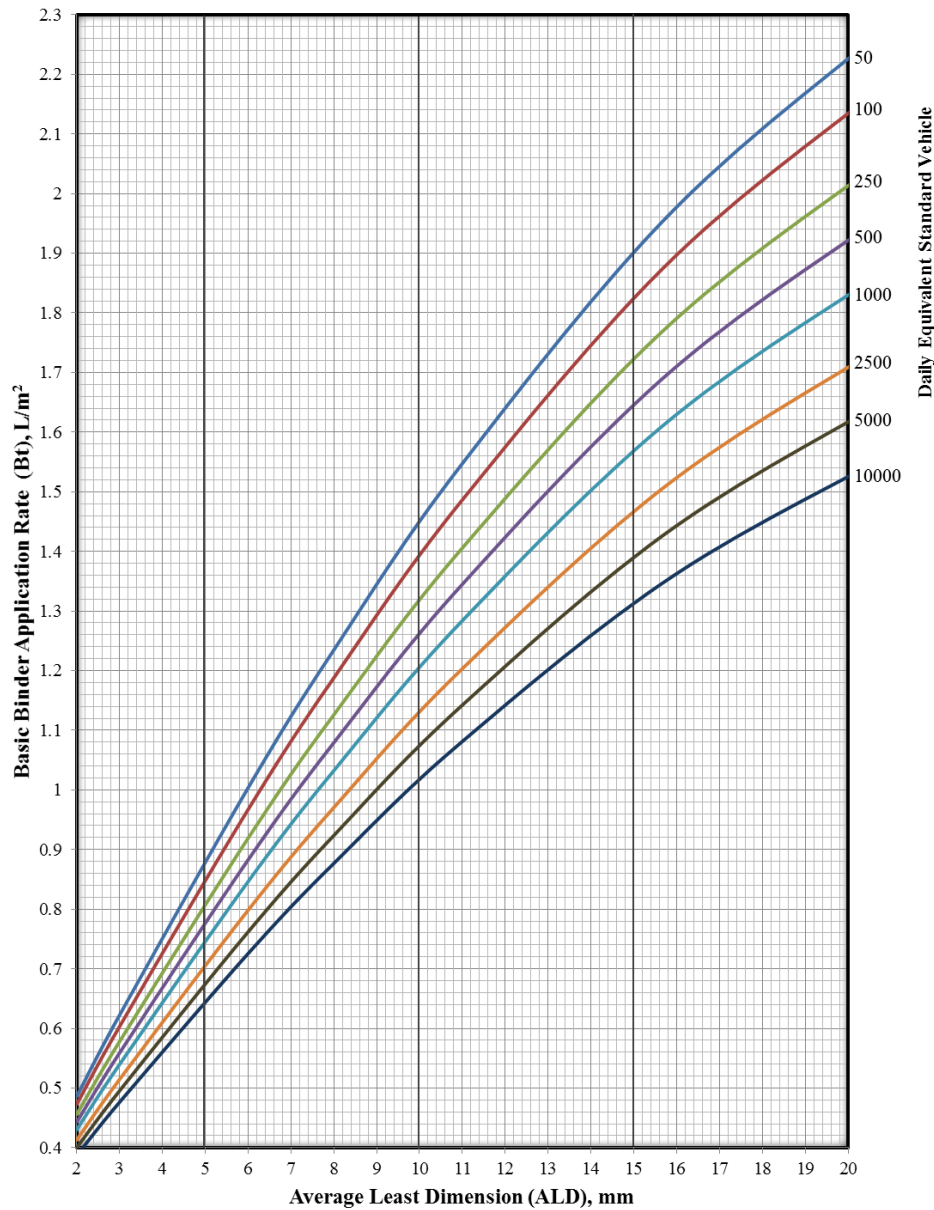


Figure 2: Chart for determining the Basic Binder Application Rate

## 2.5. Making Corrections

### 2.5.1. Aggregate Bitumen Absorption Correction ( $\Delta_{abs}$ )

Aggregates with high bitumen absorption values increase the amount of binder to be used because of extra bitumen absorbed. Correction related to bitumen absorption shall be made by the following equation.

$$\Delta_{abs} = 0,005 \times Ab_{S_b} \times ALD \quad (3)$$

Where;

$\Delta_{abs}$  = Bitumen absorption correction of the aggregate

$Ab_{S_b}$  = Bitumen absorption of the aggregate

ALD = Average Least Dimension of the aggregate

### 2.5.2. Climate Correction ( $\Delta_c$ )

Climate has a crucial importance for the performance of surface treatments. While there are more bleeding and embedment problems due to the traffic effects in warm climates, there are more stripping and raveling problems in cold and rainy climates. Therefore, climatic conditions must be taken into account while determining both class and the amount of the bitumen to be used in construction of surface treatment.

While making climate correction, booklet “Bitumen Grade Selection Maps for Hot Bituminous Mixture Paved Roads” (KGM, 2012) showing the highest and the lowest pavement temperature values is used. Climate correction will be made for the road sector designed as surface treatment according to the basic performance grading (PG). Correction factor resulting from climate shall be chosen from Table 2.

**Table 2: Selection Table of Climate Correction.**

| Basic Bitumen Performance Grading (PG)* | Climate Correction, $\Delta_c$<br>L/m <sup>2</sup> |
|---|--|
| 70-16                                   | -0.10  |
| 64-16                                   | -0.06  |
| 64-22                                   | -0.03  |
| 64-28                                   | 0  |
| 58-16                                   | 0  |
| 58-22                                   | 0.03   |
| 58-28                                   | 0.06   |
| 52-28                                   | 0.10   |

\* Bitumen performance grade just based on temperature data (without traffic and road corrections)

### 2.5.3. Correction for Surface Texture ( $\Delta_{st}$ )

The surface texture of the pavement on which the surface treatment is to be constructed affects the amount of binder to be used. While the amount of binder to be used has to be increased in coarse surfaces, it has to be decreased in bled and flushed surfaces. Surface texture depth (macrotexture) can be used as roughness level of the surface and “Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique” (ASTM E 965-96, 2006) is used to measure the macrotexture depth. The texture class of an existing surface in the design of surface treatment might be determined depending on the macrotexture depth by the help of Table 3.

**Table 3: Table for the selection of surface texture class.**

| Surface Texture Class | Texture Depth, mm |
|-----------------------|-------------------|
| Very coarse           | >2.0              |
| Coarse                | 1.5-2.0           |
| Well Textured         | 1.0-1.5           |
| Smooth                | 0.5-1.0           |
| Flushed               | <0.5              |

On the other hand, grain size of the aggregate on the existing surface and maximum grain size of the chipping of surface treatment to be constructed also may affect the amount of binder. When aggregate on the existing surface becomes coarser, gaps between the aggregates increase. If the dimension of chipping of new surface treatment is small, they might fill these gaps and if the aggregate size is greater than the gap size, need for the bitumen to be used is increased for the reason that the gaps could not be filled. This case is taken into account in the design using ratio of the maximum grain size of the chipping (D) to maximum grain size of existing surface aggregate (D<sub>o</sub>). Surface texture correction ( $\Delta_{st}$ ) is determined by using the graph on Figure 3 according to texture depth or surface texture class and D/D<sub>o</sub> ratio.

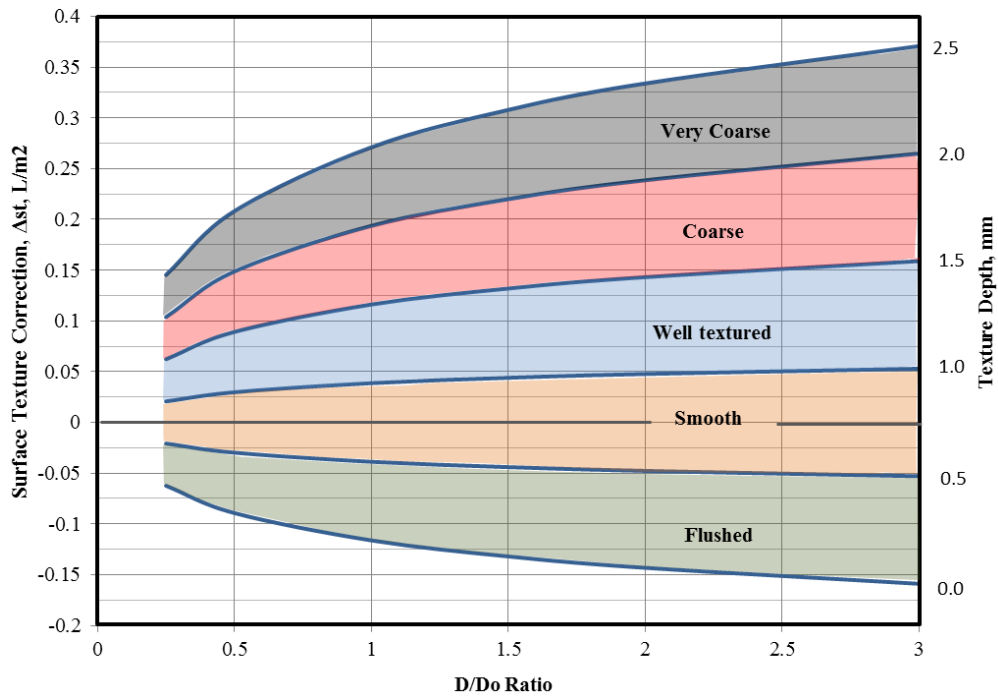


Figure 3: Graph for Surface Texture Correction.

#### 2.5.4. Correction for Surface Hardness ( $\Delta sh$ )

The hardness of the surface on which surface treatment is placed is another factor affecting the amount of bituminous binder to be used in surface treatment. Aggregate is more prone to embedment into the soft surfaces, which requires less bitumen since it increases asphalt bleeding.

The most important parameter affecting the hardness of the existing road surface is the type of pavement. The softer the existing surface is, the more aggregate embedment takes place. Whilst rigid pavements have very hard surface, bituminous pavements have a medium and primed or non-primed aggregate surfaces have low hardness values. Especially the compaction level of base layer significantly effects hardness of the surface.

Besides, a seasonal condition in which the surface treatment is constructed also affects the surface hardness. While bituminous treatments show hard characteristics in cold and frost seasons, they might show softer behaviors during the hot seasons.

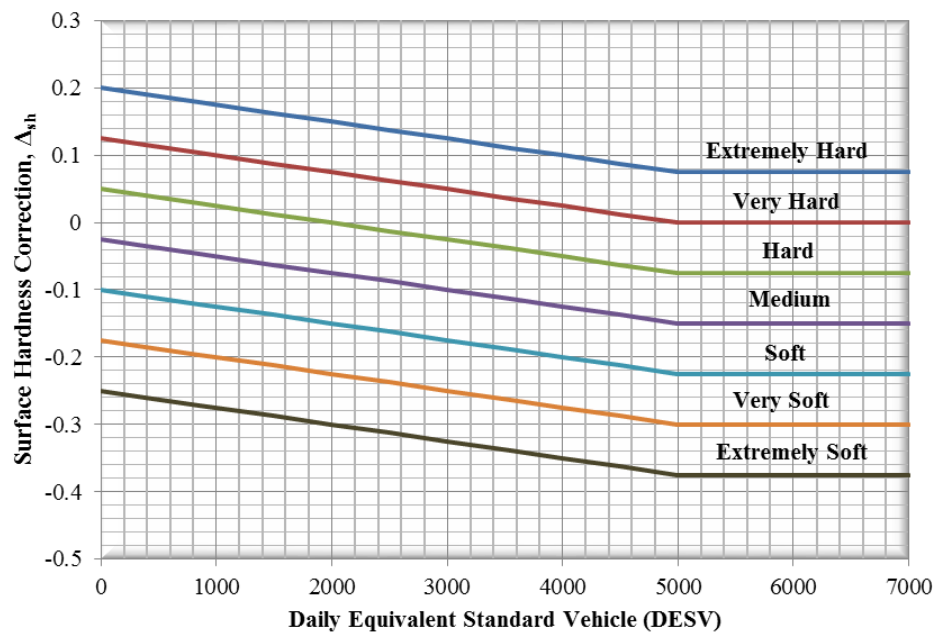


Figure 4: Graph for Surface Hardness Correction Factor.

Therefore, hardness of existing surface of the surface treatment has to be checked before the construction. Ball penetration test is one of the most common experimental methods used to determine surface hardness. It is used to measure the penetration resistance of the road surface by applying Marshall Hammer on a standard ball as a single pulse.

On the other hand, the embedment of the aggregates varies depending on the amount of traffic. After determining the hardness class of the road surface from Table 4, surface hardness correction is determined by using hardness class and DESV from Figure 4.

**Table 4: Selection table for hardness class of road surface.**

| Degrees of Surface Hardness | Surface Hardness Class | Surface Identification   | Ball Penetration Value |
|-----------------------------|------------------------|--|------------------------|
| 1                           | Extremely Hard         | Concrete Pavement or cement-treat granular base  | <0.5 mm                |
| 2                           | Very Hard              | Highly oxidized, hardened bituminous mixture pavement  | 0.5-1 mm               |
| 3                           | Hard                   | Less aged bituminous mixture pavement, more aged surface treatment   | 1-2 mm                 |
| 4                           | Medium                 | Bled bituminous mixture pavement, old surface treatment of medium-hardness, cold recycling of bituminous pavements | 2-3 mm                 |
| 5                           | Soft                   | Less smooth coated base layer, less bled surface treatment   | 3-4 mm                 |
| 6                           | Very Soft              | Smooth coated base layer, medium-bled surface treatment  | 4-5 mm                 |
| 7                           | Extremely Soft         | Very smooth coated base layer, extremely-bled surface treatment  | >5 mm                  |

Note: Surface hardness classification identification on table is given for average temperate seasonal conditions.

On asphalt surfaces one grade softer class for very hot weather conditions, and one grade harder class for cold weather conditions is chosen.

### 2.5.5. Temperature Correction ( $\Delta_T$ )

The experience gained in the construction of surface treatments demonstrates that atmospheric weather condition and air temperature at the time of application significantly affects the performance of the surface treatment. Embedment of aggregate and bitumen-aggregate adhesion decrease when the weather is cold and windy due to rapid cooling. More aggregates are embedded into the surface in hot weather than when it is in cold weather during both application and compaction under traffic. Therefore, the application rate of the binder has to be increased in applications where temperature is low and decreased in applications where temperature is high.

Turkish Road Technical Specification (KTŞ, 2013) allows the BST to be applied only when the air temperature in the shade is between 15 °C and 45 °C. In this respect, the air temperature of 30 °C has been accepted as ideal reference BST application temperature, and 1 % of the deviation from 30 °C is recommended as a temperature correction in this method. Accordingly, temperature correction ( $\Delta_T$ ) for air temperature T is determined by means of following equation.

$$\Delta_T (L/m^2) = \frac{(30-T)}{100} \quad (4)$$

### 2.6. Determination of Design Amount of Binder

After determining basic binder application rate, aggregate bitumen absorption, climate, surface texture and surface hardness together with modified bitumen factor ( $F_m$ ), Design Binder Application Rate to be used ( $B_d$ ) is determined by means of following equation for double and single layered surface treatments.



**For single layered surface treatments:**

$$B_d = \frac{B_t \cdot F_m + \Delta_c + \Delta_{abs} + \Delta_{st} + \Delta_{sh} + \Delta_T}{R} \quad (5)$$

**For double layered surface treatments:**

Double layered surface treatment here refers to second layer application of chipping immediately after first layer before permitting the traffic. The method used for the single layered surface treatments is also used for the double layered surface treatments. However, basic binder application rate has to be reduced by 15 % due to reduction in voids in the first layer of the surface treatment. Second layer basic binder application rate is found same as that of first layer, but without surface texture, surface hardness and climate corrections. Accordingly, Bituminous binder required in the first layer:

$$B_1 = \frac{0,85 \cdot B_{t_1} \cdot F_{m_1} + \Delta_{c_1} + \Delta_{abs_1} + \Delta_{st_1} + \Delta_{sh_1}}{R_1} \quad (6)$$

Bituminous binder required in the second layer:

$$B_2 = \frac{B_{t_2} \cdot F_{m_2} + \Delta_{abs_2}}{R_2} \quad (7)$$

Where;

$B_t$  = Basic binder content, L/m<sup>2</sup>

$F_m$  = Modified bitumen factor

$\Delta_c$  = Climate Correction, L/m<sup>2</sup>

$\Delta_{abs}$  = Aggregate Bitumen Absorption Correction, L/m<sup>2</sup>

$\Delta_{st}$  = Correction for Surface Texture

$\Delta_{sh}$  = Correction for Surface Hardness

$\Delta_T$  = Temperature Correction

R = Residual bitumen ratio (e.g. 0.6 for the bitumen that contain 60 % bitumen)

$F_m$  given here is modified bitumen factor and selected from Table 5. Basic binder application rate is increased when using modified binder in surface treatment.

Meanwhile, residual binder content has to be considered in design especially in case of bitumen emulsion or cut-back bitumen. In this case Design Binder Application Rate is increased in the ratio of the residual binder content (R) [3].

**Table 5: Selection table for Modified Bitumen Factor**

| Type of Surface Treatment                   | Modified Bitumen Factor , $F_m$ |
|---|---------------------------------|
| Normal Bituminous Surface Treatments        | 1.0                             |
| Modified Bituminous Surface Treatments      | 1.1                             |
| Stress Absorbing Membrane Layer (SAM)       | 1.3                             |
| Stress Absorbing Membrane Interlayer (SAMI) | 1.7                             |

While designing binder application rate for each layer in double layered bituminous surface treatments, seasonal weather condition has to be taken into consideration. In hot seasons 60%, in moderate seasons 50% and in cold seasons 40% of the total binder of both layers is recommended to use in the first layer and the rest is in the second layer. Accordingly, as “ $k_s$ ” is seasonal factor, binder content ( $B_{d_{1,2}}$ ) to be applied for each layer is determined by using following equation:

$$B_{d_{1,2}} = k_s \cdot (B_1 + B_2) \quad (8)$$

**Table 6: Selection table for seasonal factor.**

| Seasonal Conditions          | Seasonal Factor, $k_s$ |                        |
|------------------------------|------------------------|------------------------|
|                              | First Layer, $k_{s1}$  | Second Layer, $k_{s2}$ |
| Moderate Seasonal Conditions | 0.5                    | 0.5                    |
| Hot Seasonal Conditions      | 0.6                    | 0.4                    |
| Cold Seasonal Conditions     | 0.4                    | 0.6                    |

### 3. DETERMINATION OF AGGREGATE (CHIPPINGS) SPREAD RATE

Aggregate spread rate ( $M_d$ ) to be used in single layered surface treatments in this design method is determined according to the type of existing surface layer.

$$M_d = k_l \times \gamma_b \times ALD \quad (9)$$

Here,  $\gamma_b$  is the loose density of the aggregate in  $\text{ton/m}^3$ .  $k_l$  is called as layer factor and selected from Table 7. This value changes depending on the type, shape and surface characteristics of the aggregate. Bulk density of the aggregate is approximately  $1.4 \text{ kg/m}^3$  and can be determined as per TS EN 1097-3. Loose density of the aggregate is found by calculating aggregate mass placed in a cylindrical flat-bottomed vessel / the volume of the vessel ratio. Aggregate spread rate found for each layer as mentioned above does not require any correction.

**Table 7: Selection table for layer factor.**

|                |              | Layer Factor, $k_l$ |                    |
|----------------|--------------|---------------------|--------------------|
|                |              | Primed surfaces     | Non-primed reseals |
| Single Layered |              | 1.1                 | 1.05               |
| Double Layered | Second Layer | 1.05                | 1.0                |
|                | First Layer  | 0.85                | 0.8                |

### 4. CONCLUSIONS

Surface treated roads account for approximately 72 % of the road network under responsibility of General Directorate of Highways in Turkey. UK design method used for decades has given the design values and generally contradicted with what it was used in the field. This has revealed the need for a new design method which is better in performance and in representation of application. For this purpose, this new "KGM Design Method" prepared by considering the current design methods. In this proposed design method, some new concepts has been introduced for surface treatment design.

1. Terms of vehicle equivalency factor and equivalent standard vehicle have been developed for the evaluation of traffic effect in BST design.
2. A new chart method has been introduced for determination of basic binder application rate.
3. Graphical method has been developed for the use of surface texture and surface texture effects.
4. Air temperature during the construction has also been taken into account in this design method.

Compared with the existing design methods, amount of binder in the new KGM design method is less than the most commonly used Australia Design Method and more than McLeod and Shell methods. While, aggregate spread rate is almost same as in the other methods in single layered surface treatments, it is less than what it is calculated in McLeod and Shell methods in double layered surface treatments.

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