APPLICATION OF CHIP SEAL DESIGN : A Case study

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Abstract— Due to the increasing prices of road construction materials every day, road construction costs are gradually increasing in Turkey. For this reason, the low cost and easy application of chip seals make their use very attractive. As well as being a low-cost superstructure layer, it should also have high performance. A good coating design is the basis for obtaining a high-performance coating layer. For many years, chip seal design in Turkey has been realized by adapting the methods developed by other countries to the country's conditions. However, since the design values and application values did not coincide, the design methods was revised for our country. The developed "KGM Chip Seal Design Method" was created by taking into account the climate and terrain conditions in our country. Thus, the surface coating performance has improved positively.The design process of the chip seal was carried out under different climatic, terrain and material conditions using the specified design method. With the designs performed, the most appropriate material quantities to be used in the chip seal design were determined. Based on the material quantities determined, the parameters affecting the chip seal performance were evaluated and discussed.

Index Terms— Chip seal, Chip seal desing, Highway Materials

I Introduction

Surface coatings are a type of coating consisting of one or two layers applied to the existing road surface. The lifetime of chip seals is between 6-8 years on average. However, as a result of the correct selection of the materials that make up the chip seal and a low error rate during the application and curing processes, the life of the chip seal can reach up to 20 years. Otherwise, it is possible for the pavement to deteriorate within the first year after construction. A good design is needed to get the desired performance from the chip seal and to reduce the costs incurred by rebuilding the pavement every year [1].According to the data, chip seals cover 54% of the road network in Turkey. The type of coating widely used today needs to have high performance with the right design process. For this reason, the "KGM Chip Seal Design Method" was established by the General Directorate of Highways (KGM) in 2020. The design method is a revision of the designs in the literature. With this design, vehicle equivalence factors and equivalent traffic concepts were introduced for the first time in the evaluation of the traffic factor. In addition, a new abac for the determination of bitumen content and a graphic method for the use of the surface texture effect have been introduced to the literature. Chip seal design starts with the determination of surface roughness, climatic conditions, the effect of vehicle type, lane differences, seasonal factors, aggregate properties, and bitumen properties. Then the necessary calculations are made to determine the amount of aggregate and bitumen to be applied. If these points are not taken into consideration, low-performance, perishable chip seals will be formed [2].The chip seal design developed by Hanson in New Zealand in 1934-1935 is known as the first design method. All designs developed since then have been inspired by the Hanson design method. In 1953, the Hanson design method was developed and introduced by Kearby. The Kearby method was further developed in 1953 by Benson and Gallaway and in 1991 by Epps et al. In 1960 and 1969, McLoad made some modifications to the Hanson design and created new designs. Subsequently, design methods were developed in the United Kingdom (UK) (1963), McLeod (1969), New Zealand (2005), Australia (2006), and South Africa (2007) based on the Hanson design method. In Turkey, the UK method has been used for many years. However, due to the differences in design values, it has become a necessity to create a new design method according to the conditions of our country. For this reason, the design method described above was developed in 2020 [3, 4, 5]. The average of the smallest dimensions (ASD) is a common parameter in the chip seal design methods developed so far and in the design method developed for Turkey. The parameter common to all designs was used to determine the bitumen content in the Hanson method. Hanson thought that the bitumen would wrap the aggregate according to the ASD and determined the amount of bitumen accordingly. Then, they determined that variables such as climate, surface hardness, surface macro roughness, aggregate are important in design and developed a new chip seal design method by using tefse parametresi [6, 7].For many years, Turkey has used chip seal design methods developed by other countries. However, due to the differences in traffic, climate and oil resources in other countries, problems have arisen in the realization of the designs. For this reason, in order to eliminate the problems, it is envisaged to realize a surface pavement design suitable for Turkey's conditions. It is stated that with the design method to be realized, surface pavement layers with high performance and a long service life will be formed [8].Aggregates are known to tend toward their largest size due to cylinder and traffic effects. This movement of aggregates is important in determining the amount of bitumen. Aggregate orientation was investigated in order to improve chip seal performance. The study considers aggregate loss, spalling and aggregate orientation, as well as the effect of traffic on the realignment of aggregates over time. Therefore, aggregate movements were analyzed by applying image analysis, a sweep test, and a rutting test. With the study, it was seen that the aggregates were placed according to the largest edge [9].Good design is not the only parameter that affects the performance of chip seals. After a good design process for chip seals, care should be taken in the application and maintenance processes to be carried out afterwards. Otherwise, no matter how good the design process is, it is not possible to obtain a high-performance coating [10]

. II MATERIAL AND METHOD

Road characteristics were collected for 4 road segments located in different regions in Turkey. Bitumen classes were determined from KGM data according to the regions. Then the aggregate properties to be used in the design were determined (Table 1). After determination of all properties, design procedures were carried out using KGM Chip Seal Design Method. In the road sections where the design process will be applied, it will be tried to observe the effect of climate on the material between roads 1 and 2. On road sections 1 and 3, the effect of traffic volume on the amount of material is to be observed. Finally, designs were carried out on roads 1 and 4 using different aggregates. Here, the effect of aggregate properties and gradation on the amount of material to be used was trying to be determined.

Table 1: Roads to be designed and material properties

	Road-1	Road-2	Road-3	Road-4
Road length (km)	33	36,4	35	30
Road class	2x1	2x1	2x1	2x1
Project duration (Year)	10	10	10	10
Macro texture depth (mm)	1,3	1,3	1,3	1,3
Maximum aggregate diameter (mm)	19	19	19	25
Type of aggregate	Limestone	Limestone	Limestone	Limestone
Flatness index (%)	10	10	10	3,2
Aggregate loose unit weight (kg/m³)	1400	1400	1400	1420
Type of bitumen	B 100/150	B 50/70	B 100/150	B 100/150
Basic bitumen performance class [9]	PG 58-22	PG 70-16	PG 58-22	PG 58-22

2.2. METHOD

Average size of aggregates determines(AS) with the gradation curve is used to find the average size of the aggregate. Here, AS is 15.5 mm for Roads 1-2-3 and 21.5 mm for Road 4 (Fig. 1).

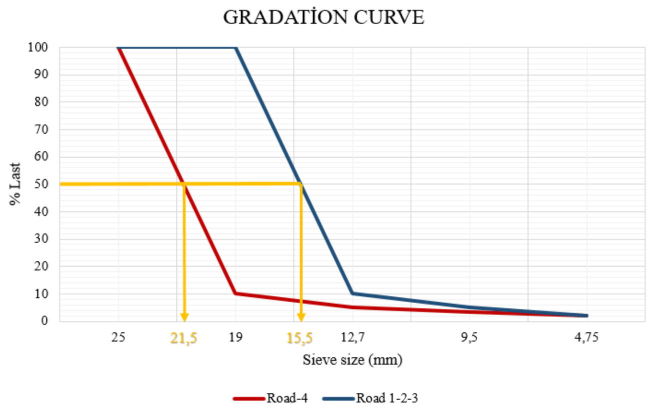

Fig. 1: Determination of aggregate average size from the gradation curve

The average of the smallest dimensions is determined using the relevant formula. Calculations were performed using the values given for all roads (Table 2).

$$ASD\ (mm) = \left[\frac{AS}{1{,}139285 + 0{,}011506\ FI}\right]$$

ASD : Average size Dimension, AS: Average Size , FI: Flatness index (%)

Table 2: Determination of the average of the smallest dimensions (ASD) using the formula.

Roads 1-2-3	Road 4
12,36 mm	18,3 mm

The annual average daily project traffic for vehicle groups and the equivalent daily traffic per lane (EDTL)for each lane are calculated. Since the traffic values of Roads 1-2-4 are close, calculations were made by considering them equal. Here, it is found as EDTL= 1133 vehicle/lane/day (Table 3). Since Road 3 has higher traffic values than the others, separate calcultions were made. For road 3, the EDTL= 3332 vehicle/lane/day (Table 4).

Table 3: Calculation of equivalent daily traffic per vehicle, Road 1-2-4

Vehicle category	AADT [10]	VEF	Velocity factor (h)	Left lane		Right lane	
				Lane dispersion factor (η)	EDTL	Lane dispersion factor (η)	EDTL
Trailer	89	6	2	1	0,5*89*6*2*1= 534	1,0	0,5*89*6*2*1= 534
Truck	118	3	1,8	1	0,5*118*3*1,8*1=319	1,0	0,5*118*3*1,8*1= 319
Bus	4	2,5	1,6	1	0,5*4*2,5*1,6*1= 8	1,0	0,5*4*2,5*1,6*1= 8
MCV	305	0,5	1,3	1	0,5*305*0,5*1,3*1=99	1,0	0,5*305*0,5*1,3*1= 99
Automobile	3141	0,1	1,1	1	0,5*3.141*0,1*1,1*1= 173	1,0	0,5*3.141*0,1*1,1*1= 173
Equivalent daily traffic per vehicle, EDTL				1.133 vehicle /lane/day		1.133 vehicle/ lane/day	
AADT: Annual average daily project traffic (KGM state roads traffic data), MCV: Medium-load commercial vehicle Vehicle equivalence factor (VEF)							

Table 4: Calculation of equivalent daily traffic per vehicle, Road 3

Vehicle category	AADT [10]	VEF	Velocity factor (h)	Left lane		Right lane	
				Lane dispersion factor (η)	EDTL	Lane dispersion factor (η)	EDTL
Trailer	321	6	2	1	0,5*321*6*2*1= 1926	1,0	0,5*321*6*2*1= 1926
Truck	304	3	1,8	1	0,5*304*3*1,8*1= 821	1,0	0,5*304*3*1,8*1= 821
Bus	16	2,5	1,6	1	0,5*16*2,5*1,6*1= 32	1,0	0,5*16*2,5*1,6*1= 32
MCV	579	0,5	1,3	1	0,5*597*0,5*1,3*1= 188	1,0	0,5*597*0,5*1,3*1= 188
Automobile	6632	0,1	1,1	1,0	0,5*6.632*0,1*1,1*1= 365	1,0	0,5*6.632*0,1*1,1*1= 365
Equivalent daily traffic per vehicle, EDTL AADT: Annual average daily project traffic (KGM state roads traffic data), MCV: Medium-load commercial vehicle	3.332 vehicle/lane/day					3.332 vehicle/lane/day	

Using the chip seal design criteria abac, the basic bitumen amount (Bt) for each lane is calculated. Bt= 1,35 L/m² for Roads 1-2. Bt= 1,26 L/m² for Road 3 and Bt= 1,71 L/m² for Road 4 (Fig. 2).

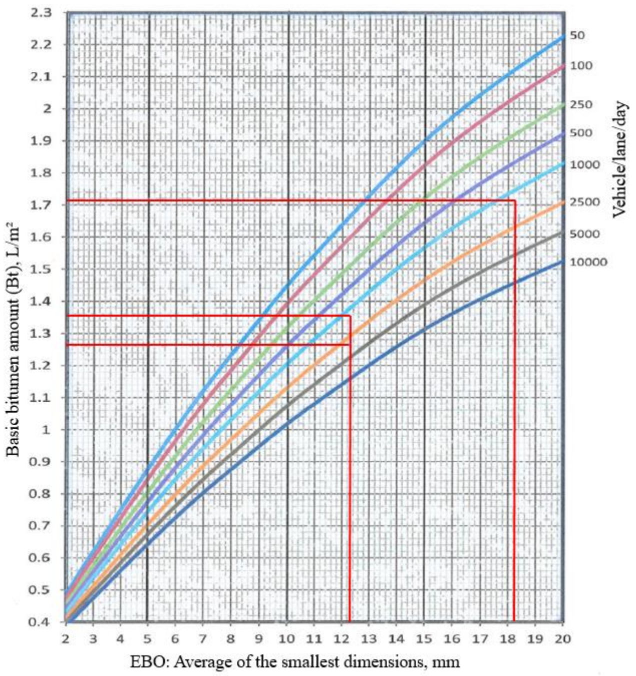

Fig. 2: Determination of basic bitumen amount [1]

With the help of the table given below, the climate correction coefficient is found according to the basic bitumen performance class. Basic bitumen performance class data is taken from KGM website. Δi = 0,03 L/m² for Road 1-3-4 and Δi = -0,10 L/m² for Road 2 (Table 5).

Table 5: C Climate correction table [1]

Basic bitumen performance class (PG)	70-16	64-16	64-22	64-28	58-16	58-22	58-28
Climate Correction, Δi (L/m²)	-0,10	-0,06	-0,03	0	0	0,03	0,06

The D/D_0 ratio on the horizontal axis of the surface texture correction graph represents D: 19 mm (the maximum aggregate size of the new surface course) and Do: 25 mm (the maximum grain size used in the existing pavement already on the road surface). The surface texture correction coefficient is found by intersecting the D/Do ratio with the texture depth in the required graph. Δy= 0.11 for all paths (Fig. 3).

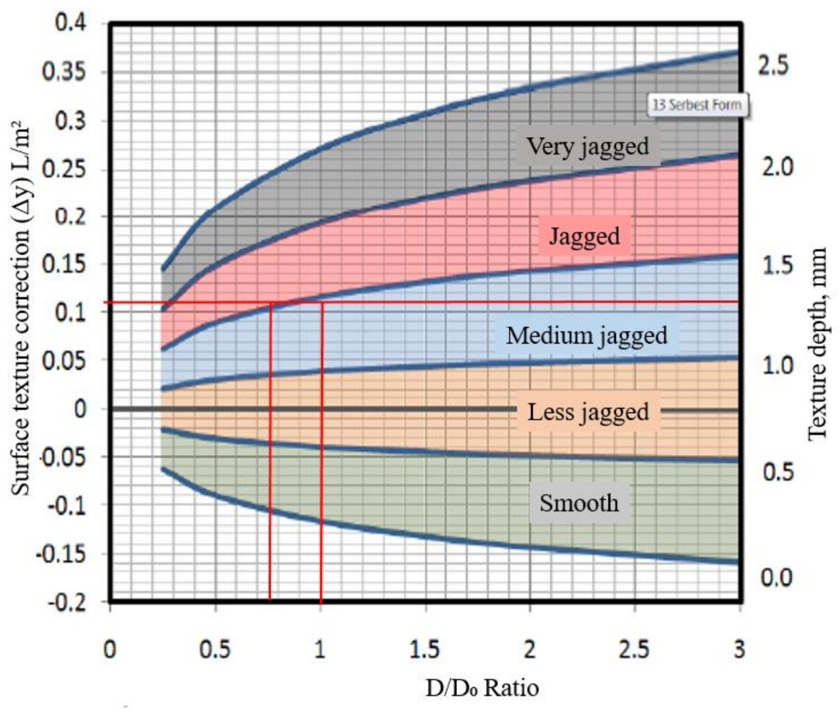

Fig. 3: Surface texture correction graph [1]

The amount of bitumen to be used in the chip seal was calculated using the formula given in Table 6. The bitumen amounts obtained were compared and discussed in the results section.

Table 6: Determination of the amount of bitumen utilization

Formula	Road 1	Road 2	Road 3	Road 4
$Bd = 100 * \frac{Bt*Fm+\Delta i+\Delta y}{R}$ [1]	1,49	1,36	1,40	1,85
Bd: Design Bituminous binder amount (L/m²), Fm: Bitumen factor (For normal bitumen: 1.0; For modified bitumen: 1.1), R: Bitumen ratio, % (e.g., 80 for emulsion containing 80% bitumen)				

The amount of aggregate to be used in the chip seal was calculated using the formula given in Table 7. The coefficient in the denominator varies according to the current condition of the surface to be covered. If the existing surface is a primed base layer, it is taken as 950; in other cases, it is taken as 1000.

Table 7: Determination of the amount of aggregate utilization

Formula	Road 1	Road 2	Road 3	Road 4
$M_d = \frac{EBO * \Gamma G}{950}$	18,2	18,2	18,2	27,35
Md: Design Aggregate Quantity (kg/m²), γg: Aggregate loose unit weight (kg/m³)				

3. RESULTS AND DISCUSSIONS

The design process for roads 1 and 2 was carried out to observe the climate effect. It was observed that the increase in temperature values decreased the amount of bitumen used in the chip seal design. Low-viscosity bitumen should be used in regions with warmer climates. Reducing the amount of bitumen in hot regions reduces bitumen vomiting.

The design results of roads 1 and 3 were analyzed to observe the traffic impact. The increase in traffic reduced the amount of bitumen used in the design. In addition, it is observed that climate and traffic effects have no effect on the amount of aggregate utilization. The reason for the decrease in bitumen amount at high traffic values is that the amount of burial due to the effect of traffic will cause vomiting and deterioration due to the amount of burial. For this reason, the amount of bitumen is reduced in the design and the vomiting deterioration is reduced.

Based on the design results for roads 1 and 4, it can be concluded that aggregate properties have a significant effect on bitumen and aggregate utilization. A decrease in the proportion of flat material in the aggregate increases the amount of bitumen used. Bitumen vomiting can occur when flat aggregates are placed in the direction of their flat dimensions under the vehicle wheel. A similar problem does not occur in chip seal, where non-flat cubic aggregates are used. The use of aggregates with a coarser grain distribution increases the amount of bitumen. The reason for this can be said to be that coarse aggregates have a larger surface area. In addition, the surface condition of the surface to be coated affects the amount of bitumen used.

Aggregate specific gravity, aggregate grain distribution, the amount of flat material in the aggregate and the condition of the surface to be applied have an effect on the amount of aggregate used. Aggregates with a coarse grain distribution were found to increase aggregate utilization. In addition, the decrease in the proportion of flat aggregate increases the use of aggregate. It can be said that the increase in aggregate loose unit weight increases aggregate utilization.

4. REFERENCES

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