Mehmet Saltan*, Betül Öksüz and Volkan Emre Uz

Use of glass waste as mineral filler in hot mix asphalt

Abstract: The use of resources is increasing due to continuous increase in world population and rapid industrialization, while natural resources are being exhausted day by day. Usage of waste materials or by-products in highway construction has substantial environmental and economic benefits. In this study, the usage of cullet and waste glass bottle dust as mineral filler material in hot mix asphalt as an alternate to traditional crushed stone dust was investigated. Optimum bitumen content was determined by the Marshall mix design method by using six different bitumen contents (4.0%, 4.5%, 5.0%, 5.5%, 6.0%, and 6.5%). With the optimum bitumen content, three different mineral filler types (cullet, glass bottle waste, and stone dust) and six different filler ratios (4%, 5%, 6%, 7%, 8%, and 9%) were used to prepare asphalt mixture samples. Samples were performed using the Marshall stability test, and the results were compared. It is concluded that cullet and glass bottle waste can be used in asphalt mixtures as a mineral filler alternate to crushed stone dust if the economic and environmental factors favor it.

Keywords: glass waste; hot mix asphalt; Marshall stability test; mineral filler.

***Corresponding author: Mehmet Saltan,** Faculty of Engineering, Civil Engineering Department, Suleyman Demirel University, 32260 Isparta, Turkey, e-mail: mehmetsaltan@sdu.edu.tr
Betül Öksüz: Faculty of Engineering, Civil Engineering Department, Suleyman Demirel University, 32260 Isparta, Turkey
Volkan Emre Uz: Faculty of Engineering and Natural Sciences, Civil Engineering Department, Science and Technology University, 01180 Adana, Turkey

1 Introduction

Growth in world population and industry requires the use of large amounts of narural resources. Using waste or by-product materials instead of natural materials may have great economic and environmental benefits. Energy consumption can be decreased by reuse of by-products instead of using natural materials. Environmental risks can be decreased by the use of by-products instead of stockpiling them.

Waste glasses are grouped as industrial solid wastes. Most of the industrial solid wastes can be used in highway constructions and road layers from top layer to subgrade. Higher performance and environmentally friendly road pavements can be constructed by the use of by-products instead of traditional materials [1].

Mineral filler has two important roles in hot mix asphalt (HMA). The first being to fill the voids between course and fine aggregates; hence, denser and stiffer layers can be obtained. The second being to provide more contact points between aggregates. Bitumen film cover filler's large surface area and stiffer contact points can be generated with the aggregates. Mostly, crushed stone dust has been utilized in hot mix asphalt as mineral filler.

The aim of this study is to investigate the usability of waste glass dust as mineral filler in HMA. A lot of research have been carried out using by-products or waste materials as mineral filler in HMA, but waste glass dust have never previously been used [2–13]. Flynn (1993) used glass waste in hot mix asphalt as a part of its granular material, and the pavement was named "glassphalt" [14]. Satisfactory results cannot be obtained by using glass waste as aggregate in HMA. Notably, a stripping problem was encountered in HMA containing more than 15% glass [1].

2 Materials and methods

In this study, crushed limestone was used as the aggregate. Coarse and fine aggregates are supplied from the Isparta Municipality Asphalt Center. Crushed stone dust and two different glass waste dusts were used as the mineral filler. Crushed stone dust was obtained by crushing limestone rocks to dust size.

Waste glasses are grouped into two categories in this study: domestic glass waste and scrap glass. Waste glasses were crushed to filler size in the laboratory.

Glasses are generally categorized into three groups: carbonate-lime, lead-alkali-silica, and borosilica [15]. The chemical composition of glass waste is given in Table 1. Specific gravity tests for coarse and fine aggregates and mineral filler were performed in accordance with the

Table 1 The chemical composition of glass waste.

Composition	Carbonate-lime	Lead-alkali-silica	Borosilica
SiO_2	70–73	60–70	60–80
Al_2O_3	1.7–2.0	–	1–4
Fe_2O_3	0.06–0.24	–	–
Cr_2O_3	0.1	–	–
CaO	9.1–9.8	1	–
MgO	1.1–1.7	–	–
BaO	0.14–0.18	–	–
Na_2O	13.8–14.4	7–10	45
K_2O	0.55–0.68	7	–
PbO	–	15–25	–
B_2O_3	–	–	10–25

ASTM C 127 [16], ASTM C 128 [17], and ASTM C 854 [18] methods, respectively. Aggregate properties are given in Table 2.

70/100 penetration asphalt cement, which was obtained from the Isparta Municipality Asphalt Center, were used for the study. Penetration tests for the bitumen were carried out according to ASTM D5-97 [19]. Specific gravity for the bitumen was also determined in accordance with ASTM D70-03 [20].

The aggregate gradation used in this study is given in Table 3 together with the General Directorate of Turkish Highways specification limits. It can be seen that the selected aggregate gradation is appropriate to Turkish Highway specification for bituminous course. The Marshall method was used for the mix design [21].

Table 2 Properties of aggregates.

Property	Value	Standard
Specific gravity of limestone coarse aggregate	2.695	ASTM C 127
Saturated specific gravity of limestone coarse aggregate	2.605	ASTM C 127
Water absorption of limestone coarse aggregate (%)	1.3	ASTM C 127
Specific gravity of limestone fine aggregate	2.72	ASTM C 128
Saturated Specific gravity of limestone fine aggregate	2.83	ASTM C 128
Water absorption of limestone fine aggregate (%)	1.12	ASTM C 128
Specific gravity of limestone filler aggregate	2.56	ASTM C 854
Specific gravity of cullet glass filler aggregate	2.44	ASTM C 854
Specific gravity of domestic glass waste filler aggregate	2.49	ASTM C 854

Table 3 Aggregate granulometry.

Sieve	Turkish specification limits (% passing)	Study values (passing,%)
19 mm (3/4″)	100	100
12.5 mm (1/2″)	83–100	91.5
9.5 mm (3/8″)	70–90	80
4.75 mm (No. 4)	40–55	47.5
2.00 mm (No. 10)	25–38	31.5
0.425 mm (No. 40)	10–20	15
0.180 mm (No. 80)	6–15	10.5
No. 200	4–10	7

Voids in mineral aggregate (VMA) are defined as the voids between aggregate particles of compacted bituminous mixtures and calculated as a percentage of the total volume.

For a given asphalt and aggregate gradation, the durability is enhanced if adequate film thickness is attained. For the given effective asphalt content, the film thickness will be greater if the aggregate gradation is coarser. This can most effectively be accomplished by decreasing or minimizing the percentage of fine content. Establishing adequate VMA during mix design and in the field application will help to establish adequate film thickness without excessive asphalt, which causes bleeding or flushing [13].

Asphalt mixtures with limestone aggregate and limestone mineral filler were prepared with a 4%, 4.5%, 5%, 5.5%, 6%, and 6.5% rate of bitumen content. The optimum bitumen content was calculated by taking the average values of the following four bitumen contents [13]:

1. Bitumen content corresponding to maximum stability
2. Bitumen content corresponding to maximum bulk specific gravity
3. Bitumen content corresponding to the median of designed limits of percentage air voids in the total mix (for 4%)
4. Bitumen content corresponding to the median of designed limits of percentage voids filled with bitumen in the total mix.

The maximum stability was obtained in 4% bitumen content, which can be easily seen in Figure 1. Relationships between bitumen contents and air voids and percentage voids filled with bitumen in the total mix are shown in Figures 2 and 3. Hence, bitumen contents corresponding to the median of the designed limits of percentage air voids (for 4%) and percentage voids filled with bitumen in the total mix (for 80%) were obtained as 6.22% and 6.46%, respectively. The maximum specific gravity value was obtained in

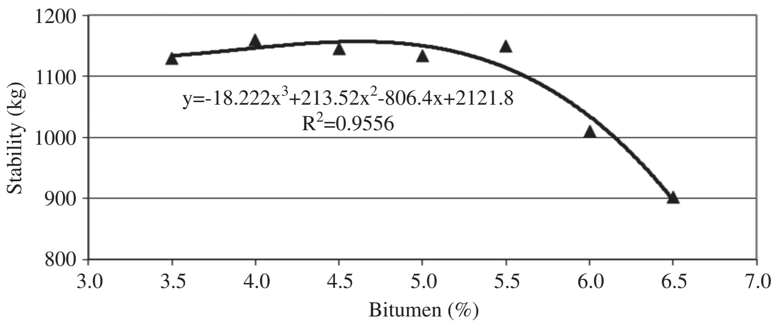

Figure 1 Marshall stability for bitumen content.

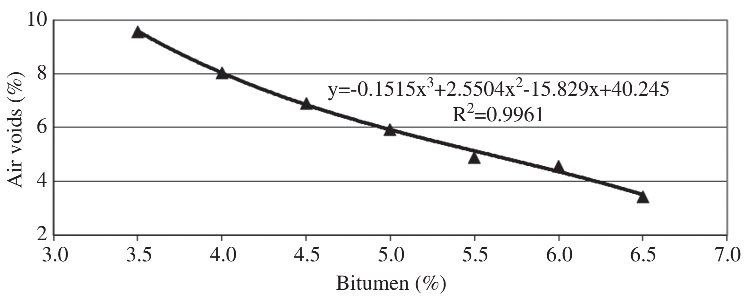

Figure 2 Relationship between air voids and bitumen content.

6.5% bitumen content. The optimum bitumen content can now be calculated as $\frac{4.00+6.50+6.46+6.22}{4}=5.80.$

The flow value reflects the properties of plasticity and flexibility of asphalt mixtures. Marshall samples, corresponding to the deformation of the load, that are broken, which represents a measure of the flow, is an indicator of the internal friction. Flow has an inverse linear relationship with internal friction [22]. The relationship between flow and bitumen content is shown in Figure 4. A linear relationship between the bitumen content and flow was obtained from the experimental results. Increasing the asphalt cement percentage also increases the flow value. Flow value in the optimum bitumen content is 3.43. The flow value falls in the specification limits.

The filler type change may affect the optimum bitumen content so that the optimum bitumen content procedure is repeated for the other filler types. As described above, the optimum bitumen contents for the mixtures with domestic and cullet glass waste filler materials were obtained as 5.94 and 5.85, respectively.

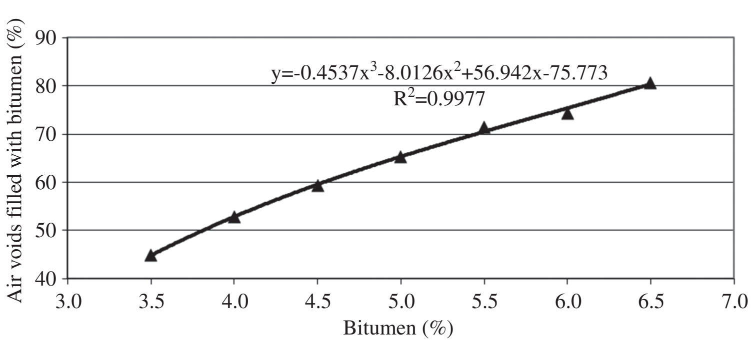

Figure 3 Relationship between air voids filled with bitumen and bitumen content.

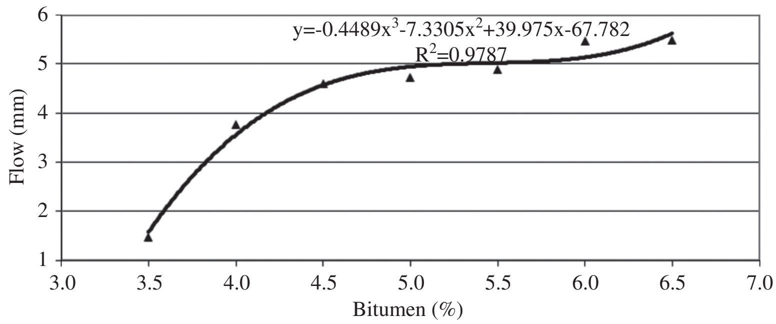

Figure 4 Relationship between flow and bitumen content for limestone mineral filler.

3 Results

3.1 Results of limestone mineral filler

In this study, not only the different filler types but also the different filler ratios (5%, 6%, 7%, 8%, and 9%) were used. Each mineral filler type and filler ratio asphalt mixtures prepared in optimum bitumen content was subjected to the Marshall stability test. The Marshall stability test results for all mineral filler types and ratios are shown in Figures 5–8.

The amount of filler should be considered carefully. When the filler amount is excessive, the mineral filler material acts as a binding material sliding over each of the other grains. This situation negatively affects the stability. When an inadequate filler amount is used in HMA, a dense layer cannot be achieved, and strong contact points cannot be generated. Optimum filler ratio should be used in order to prevent this drawback.

An increase in limestone filler ratio caused a decrease in stability (Figure 5). Maximum stability is obtained at a 5% filler content. Specific gravity and air voids filled with bitumen values are not affected by the change in mineral filler ratios (Figures 6 and 7). Air voids decrease with increasing limestone mineral filler ratios (Figure 8). Grain size of the mineral filler affects this situation. Voids in aggregates may be filled with a smaller-sized mineral filler.

Maximum Marshall stability was obtained at 5.5% filler content for limestone mineral filler (Figure 5). Specific gravity and void-filled bitumen were not affected by the change in filler content and tend to be horizontal (Figures 6 and 7). Voids filled with bitumen and voids ratios changed between 52.75% and 65.29% (Figure 7) and 3.61% and 3.86% (Figure 8), respectively. These values satisfy the specification limits.

3.2 Results of cullet glass dust mineral filler

For the change in filler ratio, the Marshall stability test results for cullet glass dust are shown in Figures 5–8. Stability increased with the increase in filler ratio up to 6%, and then, stability decreased with the increase in filler

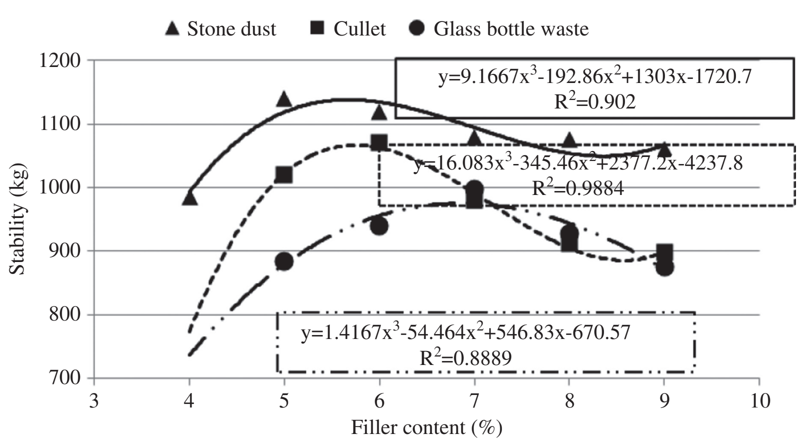

Figure 5 Relationship between Marshall stability and filler ratio.

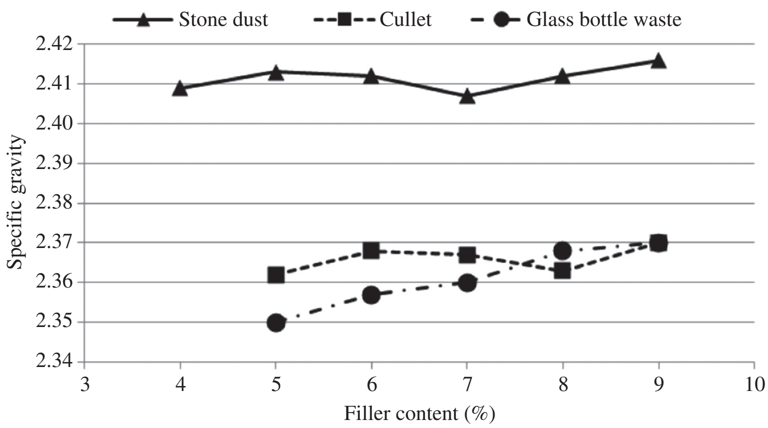

Figure 6 Relationship between specific gravity and filler ratio.

ratio (Figure 5). The Marshall samples with cullet dust filler has specific gravity values at the 2.36–2.37 band, and air voids filled with bitumen values ranged from 78% to 80%, which seems to be not affected with the filler ratio change (Figures 6 and 7). Air void ratios look stable with the change in filler ratio (Figure 8). Air void ratios are smaller for the cullet glass filler materials in comparison with the limestone mineral filler. Maximum Marshall stability was obtained for 6% cullet glass mineral filler ratio (Figure 5). Maximum specific gravity was obtained for 9% cullet glass dust (Figure 6).

3.3 Results of domestic glass waste dust mineral filler

Marshall stability test results for domestic glass waste dust mineral filler with different ratios are shown in Figures 5–8. Stability increased with the increase in filler ratio up to 7%, and then, stability decreased with the increase in filler ratio (Figure 5). Specific gravity and air voids filled with bitumen values increased with increasing mineral filler ratios (Figures 6 and 7). But air void ratios decrease with increasing filler ratios for domestic glass waste dust (Figure 8). When filler types were compared, a sharper change in air voids occurred in domestic glass waste dust filler. Maximum Marshall stability was obtained at 7% filler ratio for domestic glass waste dust (Figure 5). Maximum specific gravity was obtained for 9% domestic glass waste dust (Figure 6). Voids filled with bitumen and voids changed between 49.71% and 82.40% (Figure 7) and 4.36% and 3.55% (Figure 8), respectively. These values satisfy the specification limits. The relationship between flow and filler ratio can be seen in Figure 9 for all filler types.

4 Conclusions

In this study, the usability of cullet glass and domestic glass waste dust in HMA as mineral filler material was investigated. To define the optimum bitumen content

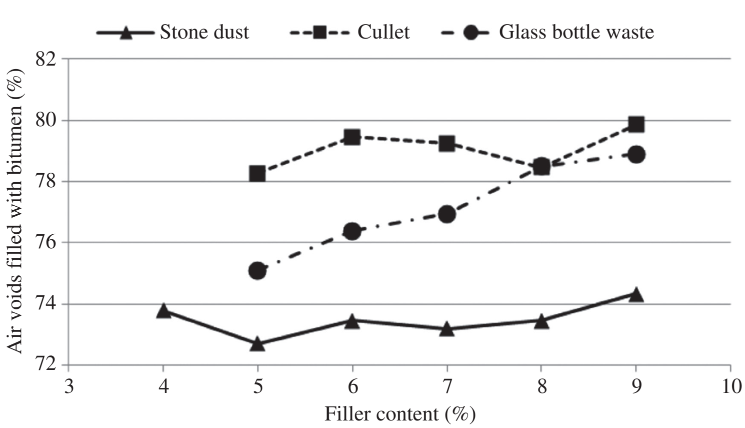

Figure 7 Relationship between air voids filled with bitumen and filler ratio.

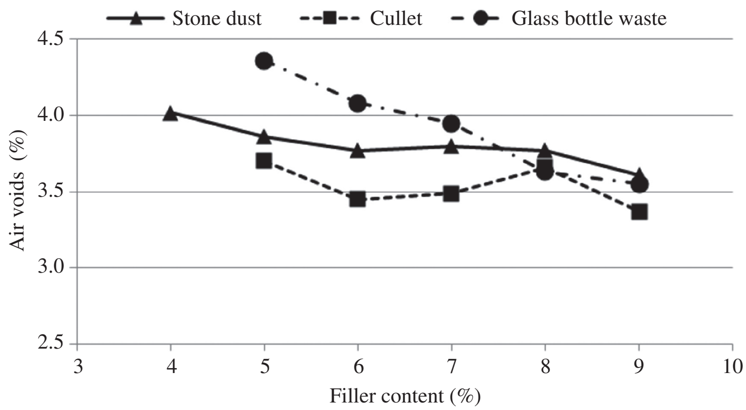

Figure 8 Relationship between air voids and filler ratio.

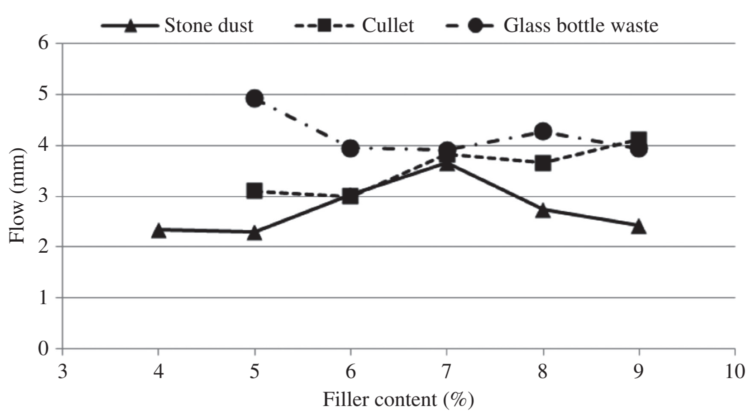

Figure 9 Comparison of flow values.

for the mixtures with limestone aggregate and limestone mineral filler, Marshall samples were prepared with 4.0%, 4.5%, 5.0%, 5.5%, 6.0%, and 6.5% bitumen contents. The optimum bitumen content was found to be 5.8%. Repeating the procedure for cullet and domestic glass dust filler materials, the optimum bitumen contents were found to be 5.85% and 5.94%, respectively. For each filler type and optimum bitumen contents, 4%, 5%, 6%, 7%, 8%, and 9% filler percentages were used in preparing the Marshall samples.

The Marshall stability and flow values for all the filler types (limestone, cullet glass, and domestic glass waste) satisfy the General Directorate of Turkish Highways specification limits. The Marshall stability values of the mixtures with cullet glass and domestic glass waste filler are slightly smaller than the mixtures with the limestone mineral filler material (Figure 5). Although using only the Marshall test method would not give appropriate results and evaluations in Turkey, the mix design of hot mix asphalts still relies on the Marshall method as in many other countries. This study will be a basis for a more detailed further research and extra test methods, such as bending, fatigue, and wearing tests can be done.

In conclusion, cullet glass and domestic glass waste dusts can be used in asphalt concrete mixtures as mineral filler materials according to the Marshall method. Using glass waste in hot mix asphalt pavements would be very useful in view of waste management.

Received June 11, 2013; accepted November 2, 2013; previously published online December 11, 2013

References

[1] Çağlar GA. Utilization of industrial waste materials in highway construction, MSc Thesis, İstanbul Technical University: Turkey, 2007.
[2] Muniandy R, Aburkaba E, Hamid H, Yunus R. *J. Eng. Appl. Sci.* 2009, 4, 54–64.
[3] Ahmedzade P, Alataş T, Geçkil T. *İMO Tech. J.* 2008, 19, 4539–4544.
[4] Ahmed H, Othman A, Mahmoud A. *Assiut University Bull. Environ. Res.* 2006, 9, 51–60.
[5] Çelik ON, Ceylan S, Kaya M. Effect of Carboniferous-Triassic Rock Dust on the Marshall Stabilities of Hot Bituminous Mixtures, *International Conference on Maintenance and Rehabilitation of Pavements and Technological Control (MAIREPAV5), Fifth Proceedings*, 2007, pp. 43–48.
[6] Üstünkol F. Investigation of usage of industrial wastes in flexible pavement, MSc Thesis, Balıkesir University, Institute of Science, Department of Civil Engineering: Balıkesir, Turkey, 2006, pp. 104.
[7] Karaşahin M, Tığdemir M, Fincanoğlu A, Saltan M. Use of pumice as filler in asphalt concrete mixture, 1st Isparta Pumice Symposium, Isparta, 1997.
[8] Karaşahin M, Terzi S. *Constr. Build. Mater.* 2007, 21, 616–620.
[9] Acar S, Tapkın S. Examination of Marshall sample's properties prepared using Portland cement, 2nd National Asphalt Symposium, 1998, pp. 95–104.
[10] Kandhal PS, Lynn C, Parker F. *Characterization tests for mineral fillers related to performance of asphalt paving mixtures, transportation research record*, Auborn University: Auborn, AL, 1998, pp. 101–110.
[11] Güngör MM. An investigation on the use of Afşin-Elbistan fly ash in flexible pavement as mineral filler, M.Sc. Thesis, Fırat University: Elazığ, Turkey, 1996.
[12] Lav A, Sütaş İ. *İMO Tech. J.* 1993, 4, 631–642.
[13] Uzun I, Terzi S. *Constr. Build. Mater.* 2012, 31, 284–288.
[14] Flynn L. *Roads Bridges* 1993, 31, 59–61.
[15] Sherwood P. *Alternative Materials in Road Construction*. 2nd ed., Thomas Telford: Heron Quay, London. DOI: 10.1680/amirc2e.30312.
[16] ASTM C 127. Test Method for Specific Gravity and Adsorption of Coarse Aggregate. Annual Book of ASTM Standards USA, 1992.
[17] ASTM C 128, 1992. Test Method for Specific Gravity and Adsorption of Fine Aggregate. Annual Book of ASTM Standards USA.
[18] ASTM C 854, 1992. Test Method for Specific Gravity and Adsorption of Mineral Filler. Annual Book of ASTM Standards USA.
[19] ASTM D5-97, 2003. Standard Test Method for Penetration of Bituminous Materials. Annual Book of ASTM Standards, USA.
[20] ASTM D70-03, 2003. Standard Test Method for Specific Gravity and Density of Semi-Solid Bituminous Materials (Pycnometer Method). Annual Book of ASTM Standards, USA.
[21] ASTM D1559-89, 1992. Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus. Annual Book of ASTM Standards, USA.
[22] Umar F, Ağar E. 1991. *Pavement structure*, İstanbul: İstanbul Technical University, Civil Engineering, Faculty Press [in Turkish].