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Kolemanit atıkların sıcak karışım asfalt betonda agrega olarak değerlendirilmesi

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Anahtar Kelimeler
Marshall stabilitesi
Kolemanit
Atık
Agrega
Esnek üstyapı

Özet: Bu çalışmada, blok halindeki kolemanit malzemenin işlenmesi aşamasında ortaya çıkan atık kolemanitin sıcak karışım asphalt betonda agrega olarak kullanılabilirliği araştırılmıştır. Bu amaçla dört farklı agrega gurubu kullanılarak asphalt beton numuneler hazırlanmış ve optimum bitüm miktarı belirlenmiştir. Öncelikle sadece kireçtaşı agregası daha sonra ise sadece kolemanit agregası aynı agrega gradasyonu içerisinde kullanılmıştır.Çalışmanın bir sonraki aşamasında ise kaba ve ince agrega gradasyonu kireçtaşı ve kolemanit agrega yer değiştirilerek marshall numuneleri hazırlanmış ve marshall stabilite testine tabi tutulmuştur.
Deney sonuçları incelendiğinde kireçtaşı agregası ile hazırlanan numunelerin en yüksek Marshall stabilitesini verdiği, bunun yanında colemanite agregası kullanılarak hazırlanan diğer numunelerin de (sadece kolemanit, kolemanit kaba-kireçtaşı ince, kolemanit ince kireçtaşı kaba) şartname limitlerini sağladığı görülmüştür. Sonuç olarak kolemanit atıklarının yaygın olduğu bölgelerde taşıma maliyetlerinin kireçtaşına göre daha uygun olması durumunda kolemanit atıklarının asphalt beton karışımlarda kireçtaşı agregası yerine kullanılabileceği sonucuna varılmıştır.

Evaluation of colemanite waste as aggregate hot mix asphalt concrete

Keywords
Marshall stability
Colemanite
Waste
Aggregate
Flexible Pavement

Abstract: In this study usability of waste colemanite which is obtained after cutting block colemanite for giving proper shape to blocks as an aggregate in hot mix asphalt. For this aim asphalt concrete samples were prepared with four different aggregate groups and optimum bitumen content was determined. First of all only limestone was used as an aggregate. After that, only colemanite aggregate was used with same aggregate gradation. Then, the next step of the study, Marshall samples were produced by changing coarse and fine aggregate gradation as limestone and colemanite and Marshall test were conducted.
When evaluated the results samples which produced with only limestone aggregate gave the maximum Marshall Stability value. When handled other mixture groups (Only colemanite, colemanite as coarse aggregate-limestone as fine aggregate, colemanite as fine aggregate-limestone as coarse aggregate) all groups were verified specification limits. As a result, especially in areas where there is widespread colemanite waste, if transportation costs did not exceed the cost of limestone, colemanite stone waste could be used instead of limestone in asphalt concrete mixtures as fine aggregate.

1. Introduction

Asphalt concrete is the most commonly used material in pavement because of its superior service performance in providing driving comfort, stability, durability and water resistance. The escalating cost of materials and energy and lack of resources available have motivated highway engineers to explore new alternatives in building new roads [1].

One hundred million tons of aggregate is used each year in road construction in Turkey. The most

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important qualities of these aggregates are mechanical strength, service life, and safety and environmental aspects on road pavement layer construction [2]. Turkey, like Portugal, Spain, Italy, Greece, Iran and Pakistan, has an important place in natural stone production. The types of natural stone in Turkey number more than 250. Approximately one hundred of these stones are well known and regularly in demand in the international market [3].

Many natural stone or waste material for use as aggregate or filler in hot mix asphalt concrete has been investigated: asphaltite [1], basalt [3-4], hydrated lime [5], recycled fine aggregates powder [6], waste ceramic Materials[7], coarse recycled aggregates [8], recycled waste lime [9], cleaned oil-drill cuttings [10], and marble dust [11].

Boron and boron composites obtained from two main ore, which are tinkal ($Na_2O.2B_2O_3.10H_2O$) and colemanite ($2CaO.3B_2O_3.5H_2O$) also, which have huge reserve in Turkey. In Turkey huge tinkal sources were in Kırka and important colemanite sources were in Emet and Bigadiç. Production of boron minerals, composites and derivatives conducted by 5 company subordinate to Eti Boron anonymous company. Other important boron mineral that is Üleksit ($NaCaB_5O_9.H_2O$) was produced in Bigadiç [12].

Crystallized boron looks like diamond in terms of optical and appearance features and as hard as diamond. Recently country, which has boron reserves all around the world, is Turkey with the rate of 72%. Portions of important producer countries, Turkey, U.S., Russia and other countries were given respectively 33%, 28%, 23% and 16%. After 40 years there wouldn't be boron mine except Turkey in case of continue with this production speed [13].

Colemanites ($Ca_2B_6O_{11}.5H_2O$) crystallize in the monoclinic system. Hardness of the colemanite is 4-4.5 and specific gravity is 2.42 gr/cm3. Content of B_2O_3 is 50.8%. Boron is the most common in its composites. There are so many sources in the U.S. and Turkey like Emet, Bigadiç and Kestelek [12].

Boron minerals and derivatives that found common application area in so many industry area called 21 century's petroleum and important in the upgrade of the life standards is increasing day by day. Although boron substitutes another product in some conditions, in recent conditions the lack of any other mineral substitute boron in terms of quality and cheapness and being important in terms of strategically make boron important position.

Borate mining in Turkey is in form of open-pit form, after enrichment process complexity free (washing, distribution and classification by size) obtained boron ores were made available in many industrial area.

In our country which has 33% production portion in the world markets, boron concentrate production is conducted by Eti Company in Eskişehir-Kırka, Kütahya-Emet, and Balıkesir-Bigadiç and Bursa-Kestelek plant. Various researchers report that there is a 600.000 metric ton/year waste in these plants [14].

Fast production and consumption growth, which is requirement of our age coming with so many problems brought for the assessment of work that waste as a source of secondary raw materials which can be alternative to the sources of raw materials. Although works in cement, ceramic and various areas about using waste colemanite products [15, 16, 17, 18], there isn't any work about using waste colemanite in asphalt concrete.

In this study, the effect of the using colemanite aggregate in hot-mix asphalt pavements was investigated. Aggregate samples used in the study were taken in Isparta province and was used as a coarse and fine aggregates in asphalt concrete mixtures.

2. Materials and Experiments

2.1. Aggregates

Crushed limestone and waste colemanite aggregates were used in asphalt mixtures. Aggregate material tests were carried out based on American Standards, in order to obtain the physical and mechanical characteristics of the materials to be used in the mixtures. Aggregate ratios used for binders are given in Fig. 1. Crushed limestone was obtained from quarries around Isparta which are mainly used for highway construction. The aggregate properties were given in Table 1.

Table 1. Properties of aggregate used in the tests

Sieve Diameters	Properties	Standard	Limestone Aggregate	Colemanite Aggregate
4.75-0.075 mm	Specific gravity (g/cm^3)	ASTM C 127-88 [19]	2.830	2.460
	Water absorption (%)		0.130	3.300
25-4.75 mm	Specific gravity (g/cm^3)	ASTM C 128-88 [20]	2.605	2.380
	Water absorption (%)		2.800	1.700
	Abrasion loss (%) (Los Angeles)	ASTM C 131 [21]	20.38	34

In the study, aggregate grading curves for asphalt mixtures were obtained from Turkish Highway Construction Specifications (Fig.1) [22]. Sieve analyses were carried out and available grading curve for the aggregate used in the study was close to binder layer course as shown in Fig. 1.

Study contains 4 different groups of sample preparing steps. Different combinations tried for used limestone and colemanite aggregates and tried to find best results. For this reason in the study, samples which prepared with only limestone aggregate is called (LA), samples which prepared with limestone as coarse aggregate and colemanite as fine aggregate is called (LC), samples which prepared with colemanite as coarse aggregate and limestone as fine aggregate is called (CL) and the last samples which prepared with only colemanite is called (CA).

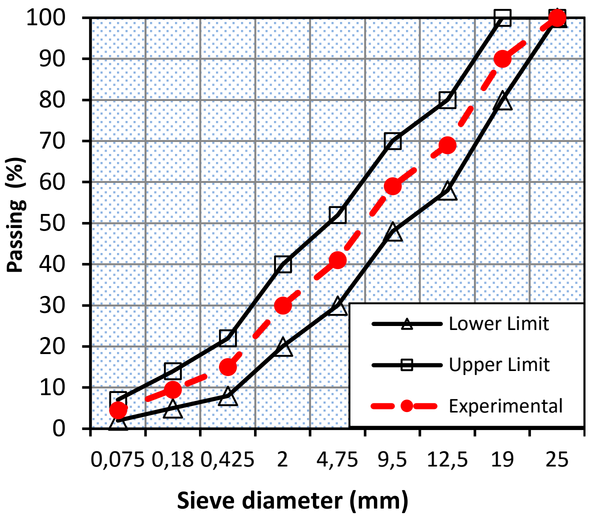

Figure 1. Gradation curve of the aggregates used in mixture

Scanning Electron Microscopy (SEM) images of the limestone and colemanite samples were given in Fig. 2. Limestone samples in particular are granular whereas colemanite samples have combined grading.

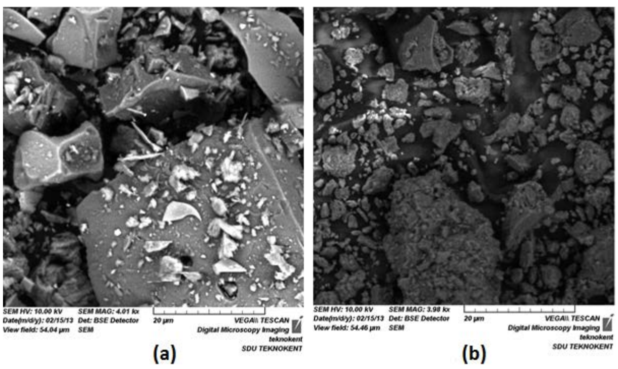

Figure 2. SEM analysis results of colemanite (a) and limestone (b) samples

Chemical composition of colemanite aggregate was given in Table 2.

Table 2. Chemical properties of Colemanite [23]

B_2O_3	39.8
CaO	26.59
SiO_2	5.56
Al_2O_3	0.17
Fe_2O_3	0.032
MgO	2.81
SO_3	0.24
SO_4	0.29
Na_2O	0.15
As_2O_3(ppm)	32
As(ppm)	24.24
SrO	1.19

2.2. Bitumen

In the Marshall samples, 60–70 penetration bitumen was used. The physical characteristics of this selected bitumen were given in Table 3.

Table 3. Basic physical characteristics of the bitumen

Characteristics of Bitumen		
Test Name	Average Values	Standard
Penetration (25 °C)	60-70	ASTM D5 [24]
Flash Point	180°C	ASTM D92 [25]
Fire Point	230 °C	ASTM D92 [25]
Softening Point	45.5°C	ASTM D36 [26]
Ductility (5 cm/minute)	>100 cm	ASTM D113 [27]
Specific Gravity	1.030	ASTM D70 [28]

3. Experimental Tests

Asphalt mixtures were prepared in accordance with the technical specifications required by Highway General Directorate of Turkey [22].

Asphalt concrete samples were prepared in five different bitumen content (BC) (4%, 5%, 6%, 7%, 8%) and these samples were tested with Marshall Stability (MS) for determining the amount of optimum bitumen. Three samples were prepared for each fraction. In addition, prepared samples with the coarse aggregate as limestone and fine aggregate as colemanite mixtures, and vice versa, the stability of these mixtures were determined. Totally 60 (4x5x3) samples were prepared and MS, flow value, void volume values (Vh), void percentages (Vf) and voids in mineral aggregate (VMA) values were determined.

The Marshall Test method was used to determine the optimum percentage of bitumen. Marshall Samples were prepared using the same aggregate gradation with 4, 5, 6, 7, and 8 percent rates of bitumen.

The samples were prepared with colemanite and limestone aggregate and optimum bitumen content was then determined by Marshall Stability Test procedure. In addition, the coarse aggregate (upper No 4 sieve) as limestone and fine aggregate (under No 4 sieve) as colemanite mixtures, and vice versa, prepared in the stability of these mixtures were determined.

4. Test Results

The optimum bitumen content for the mix design was determined by taking the average value of the following four bitumen contents taken from the above graphs.

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 (i.e. 4%)
4. Bitumen content corresponding to the median of designed limits of percentage voids filled with bitumen in the total mix (i.e. 80 %)

Bitumen contents calculated based on graphs and using Asphalt Institute Method as mathematically.

Limestone optimum bitumen content:

$$\frac{4+6+5.4+5.8}{4} = 5.3$$

Table 4. Optimum bitumen calculation table belong to groups

Groups	Dp-BC (%)	Vh-BC (%)	Vf-BC (%)	MS-BC (%)	Average Bitumen Content (%)
LA	6	5.4	5.8	4	5.3
LC	8	7.6	7.4	7	7.50
CL	8	8.2	8.2	4	7.10
CA	6	7	7.6	6	6.65

Calculated optimum bitumen contents for all groups were shown in Table 4.

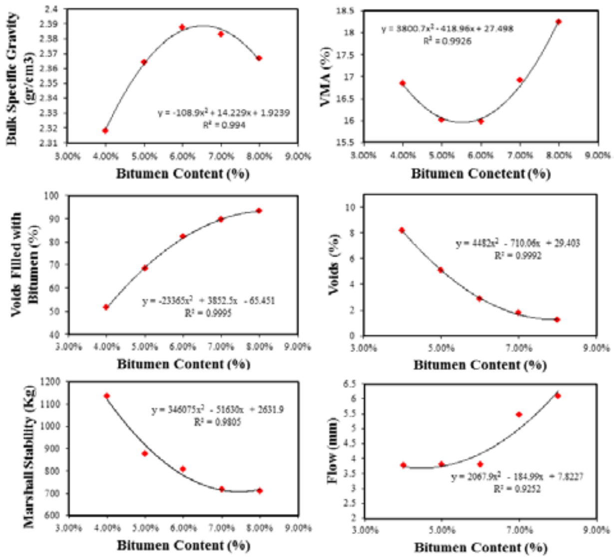

Figure 3. Marshall mix design values for LA

The flow value corresponding to this ratio is 3.95, which is under the maximum values in the specification (Fig. 3).

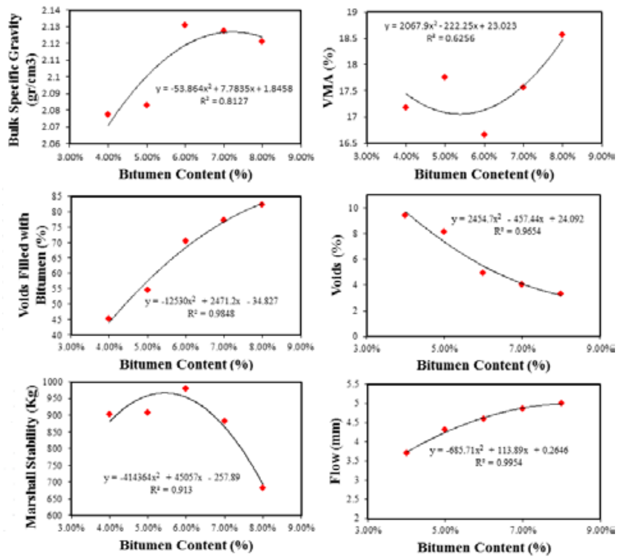

Figure 4. Marshall mix design values for CA

The flow value corresponding to this ratio is 4.5, which is over the maximum values in the specification (Fig. 4).

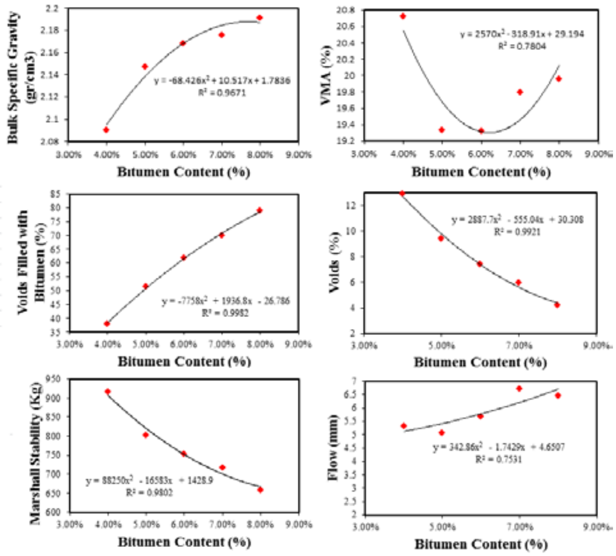

Figure 5. Marshall mix design values for CL

The flow value corresponding to this ratio is 6.4, which is over the maximum values in the specification (Fig. 5).

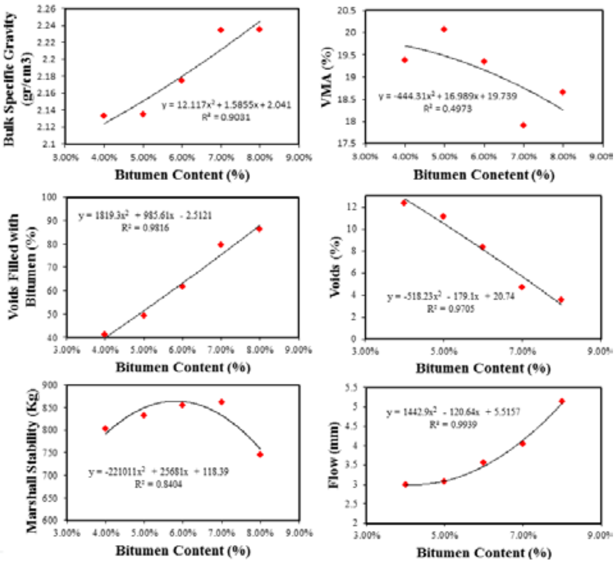

Figure 6. Marshall mix design values for LC

The flow value corresponding to this ratio is 4.3, which is over the maximum values in the specification (Fig. 6).

In this way, an asphalt concrete mix according to the rate determined in the bitumen characteristics was carried out to desired specifications.

When evaluated all groups in themselves optimum bitumen contents were determined basis on the groups. Making correlation graphs and being good correlation among the values is fundamental for conduct this process. As a result of graphs R^2 among bitumen content, MS, Flow, Vf, Vh and Dp obtained correlation percentages was given in Table 5.

Table 5. Correlation percentages of physical properties-bitumen content on the basis of group

Group	Dp-BC	Vh-BC	Vf-BC	VMA-BC	MS-BC	Flow-BC
LA	0.9940	0.9992	0.9995	0.9926	0.9805	0.9252
LC	0.9031	0.9705	0.9816	0.4973	0.8404	0.9939
CL	0.9671	0.9921	0.9982	0.7804	0.9802	0.7531
CA	0.8127	0.9654	0.9848	0.6256	0.9130	0.9954

5. Research and Finding

As shown in the figures, uniform aggregate type mixtures gave good stability results. The best stability was obtained from using only limestone aggregate. When examining Marshall Stability results of samples produced with only colemanite aggregate results proved the technical specification limits. Also samples produced with colemanite as coarse aggregate and limestone as fine aggregate proved the limits. But it should be considered that this mixture needs more bitumen content.

When examining Marshall Stability results of all mixture group samples, all samples even proved the specification limits there is certain differences among the groups. Looking at the overall picture LA group with 4% bitumen content has the highest stability value. But if the graph were examined more LA group with growing bitumen content had loss of stability.

When examining graphs for 4% bitumen content CA and CL groups have almost same stability values. But continuous graph shows CA group has parabolic inclination stability, CL group even has lower stability but it is the same with LA group. When LC group was examined there is close to the parabolic inclination and lowest stability value obtained for this group. While LC group has maximum 860 kg stability value, the highest stability value which is 1135 kg, was obtained for LA group (Fig. 7).

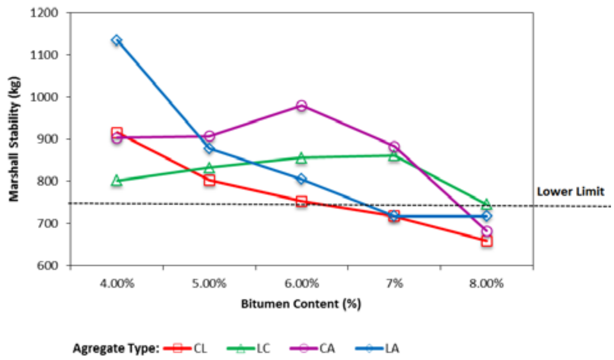

Figure 7. Relationship of stability and bitumen content

For a given asphalt and aggregate mixture, 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 fines. Establishing adequate Voids in Mineral Aggregate (VMA) during mix design, and in the field, will help establish adequate film thickness without excessive asphalt bleeding or flushing [29].

When Vf graphs among groups examined there is an increase in Vf values with the increase of bitumen content of all groups (Figure 8). This is an expected condition. Because of voids will be covered more bitumen with increase of bitumen content.

When the graph examined all groups proved the specification lower and upper limits. But it is required to say that if considered Vf value must be between 65-75% proving this with lowest bitumen content could help the eliminate financial lost. When considering this condition it can be said that LA group get the optimum Vf value with lowest bitumen content. While 5% BC enclose the Vf limit values in LA group, this is 6% in CA group, 7% in CL group and last 6.5% in BC group.

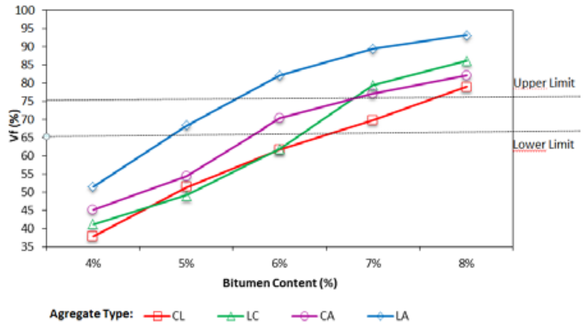

Figure 8. Relationship between voids filled with bitumen and bitumen content

When looking at the Fig. 9, there is linear decrease for all groups. When looking the figure for 4% BC there is maximum void content (Vh) in CL group, latter in LC, the third in CA and the minimum in LA group. Maximum Vh value is 12.92% with the 4% BC and the minimum is 1.23% with the 8% BC.

When looking at the figure all groups proved the specification lower and upper limits. Vh value should be in accordance with 4-6%, LA group proved limit values with approximately 5% BC. CA group proved specification limits with 6-7% BC. LC group was in limit values with 7% BC and CL group proved limit values with 7-8% BC.

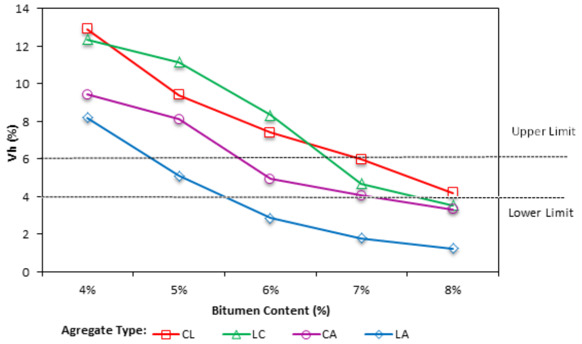

Figure 9. Relationship between air voids and bitumen content

Flow value reflects the properties of plasticity and flexibility of asphalt mixtures. Marshall Samples corresponding to the deformation of the load are broken, which represents a measure of the flow, and also the value of mixing and flow with the value of the internal friction. Flow has a linear inverse relationship with internal friction [30]. Fig. 10 shows the relationship between flow and bitumen content. Flow of the mixture with asphalt bitumen, as a result of the experiment showed a linear relationship. Increasing the asphalt cement percentage also increases the flow value.

When considering Figure 10 it is said that there is a linear increase in graphs for all groups. If considered limit values should be in accordance with 2-4% some groups were out of limits. Especially in CL group used colemanite as coarse aggregate and limestone as fine aggregate flow values exceeded the limits for all bitumen content and bitumen contents were among 5-6.5% CA group was in limits for only 4% bitumen content with 3.7% flow value.

When looking the figure for 4% BC there is maximum void content (Vh) in CL group, latter in LC, the third in CA and the minimum in LA group. Maximum Vh value is 12.92% with the 4% BC and the minimum is 1.23% with the 8% BC. Flow values proved the specification limits in LA group with the 4, 5 and 6% bitumen content but the limits were exceeded up to 5% and 6% with 7% and 8% bitumen content. In flow graph, the noticeable thing was flow values were in limit values with four bitumen content in LC group, the limit was exceeded just 8% bitumen content.

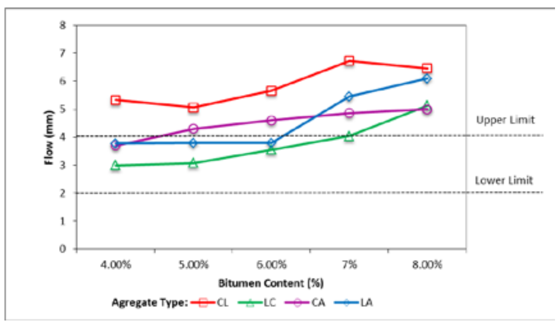

Figure 10. Relationship between flow and bitumen content.

6. Conclusions

In this study, the colemanite waste stones cutting for giving proper geometric shape were investigated the availability of the using as aggregate in asphalt mixtures.

First of all, colemanite stone and limestone samples with the same grading curve were prepared. The Marshall Stability test was applied to find the optimum bitumen percentages. As a result of the test, samples with limestone aggregate, 5.3%, and 6.65% colemanite stone aggregate of the specimen were found to be the optimum percentages of bitumen. Colemanite aggregate samples were shown by the need for more bitumen.

But this isn't forgotten that in a sense there is stabilization in bitumen contents if the colemanite aggregate which has lower unit weight used fewer amounts to obtain samples which have same volume. There are benefits if it is researched detailed in later studies. In our study we just emphasized that whether the colemanite aggregate give successful results in hot mix asphalt.

Then, the Marshall Stability test samples having the limestone coarse aggregate and colemanite fine aggregate, and vice versa were prepared changing the bitumen content from 4 to 8%. As a result of the experimental study, even proving the specification limits for MS value in all groups, highest stability value was obtained in LA group. While obtained maximum stability value is achieved 1135.2 kg in LA group, it was 980.1 kg in CA group and 861.26 kg in LC group and this was the minimum stability value on the basis of groups. And it was 915.6 kg in CL group. Lowest stability value was 658.605 kg in CL group. When examining all groups in themselves minimum stability value was 717.655 kg in LA group, 681.72 kg in CA group and 745.67 kg in LC group.

As a result, especially in areas where there is widespread waste colemanite, if transportation costs do not exceed the cost of limestone, waste colemanite stone can be used instead of limestone in asphalt concrete mixtures as fine aggregate.

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