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EVALUATION OF ZEOLITE AND PUMICE WASTE AS MINERAL AGGREGATE AND FILLER FOR PRODUCING LIGHTWEIGHT ASPHALT CONCRETE MIXTURES

Serdal TERZI*[1], Esra Mine BUYUKDOGAC[2]

[1]Suleyman Demirel University, Engineering Faculty, Dept. of Civil Engineering, Isparta, Turkey
[2]Suleyman Demirel University, Graduate Student School of Natural and Applied Sciences, Prog. of Civil Engineering, Isparta, Turkey

Keywords

Lightweight Asphalt Concrete,
Liquid Anti-strip additive,
Pumice,
Waste,
Zeolite.

Abstract

This paper focused on the use of pumice and zeolite waste as aggregate materials for producing lightweight asphalt concrete (LAC) mixtures. The samples having pumice, zeolite and limestone aggregate materials were prepared for an optimum bitumen content, optimum Liquid Anti-strip (LAS) additive ratio (0.4, 0.5, 0.6, 0.8, 0.9, 1.0, and 1.1 %), and bitumen type (50/70 and 160/220) determined following the Marshall Mixture design procedure. Then, LAC mixes were prepared with limestone used as the coarse aggregate, pumice and zeolite used as fine aggregate. Afterwards limestone used as the fine aggregate, pumice and zeolite used as coarse aggregate. The stability of the mixtures was determined with the Marshall Stability tests. Zeolite and pumice were also used as mineral filler in LAC mixtures. Optimum mineral filler ratio and physical properties were determined. In general, pumice and zeolite aggregate mixtures had lower stability in comparison to limestone aggregate mixtures. These wastes can be applied as very thin wearing layer for increasing friction, to prevent pavement layers from water infiltration, and as overlay with 25-30 mm above old pavement. Because these waste materials have very low weights, they can be used as wearing layer in paving parking areas and non-heavy weight vehicle traffic in roads. The importance of using waste materials and lightweight aggregates is to reduce the environmental impact.

HAFİF ASFALT BETONU KARIŞIMLARIN ÜRETİMİ İÇİN ZEOLİT VE POMZA ATIKLARININ MİNERAL AGREGA VE MİNERAL FİLLER OLARAK DEĞERLENDİRİLMESİ

Anahtar Kelimeler

Atık,
Hafif asphalt,
Pomza,
Sıvı Soyulmama Katkısı,
Zeolit.

Öz

Bu çalışmada, hafif asphalt betonu (LAC) üretilmesi amacıyla pomza ve zeolit atıklarının agrega olarak kullanımı incelenmiştir. Pomza, zeolit ve kireçtaşı agregaları ile asfalt numuneler hazırlanmış ve optimum bitüm içeriği, optimum likit soyulma önleyici (LAS) katkı oranı (%0.4, 0.5, 0.6, 0.8, 0.9, 1.0 ve 1.1) ve bitüm tipi (50/70 ve 160/220) Marshall Karışım dizaynına göre belirlenmiştir. Daha sonra, kaba agrega olarak kireçtaşı, ince agrega olarak pomza ve zeolit kullanılarak bir karışım, kaba agrega olarak pomza ve zeolite, ince agrega olarak kireçtaşı kullanılarak başka bir karışım hazırlanmıştır. Karışımların dayanımları Marshall Stabilite testi ile belirlenmiştir. Ayrıca zeolit ve pomza LAC karışımlarda filler olarak kullanılmıştır. Optimum mineral filler oranı ve fiziksel özellikleri belirlenmiştir. Genel olarak, pomza ve zeolit agrega karışımları kireçtaşı ile kıyaslandığında düşük dayanım göstermiştir. Bu atıklar, sürtünmeyi artırmak amacıyla ince aşınma tabakalarında, su sızıntılarını önlemek amacıyla ve eski üstyapıların üzerine 25-30 mm kalınlığında takviye tabakası olarak kullanılabilir. Hafif olmalarından dolayı bu malzemeler otoparklarda aşınma tabakası olarak ve hafif trafik olan yollarda

* İlgili yazar / Corresponding author: serdalterzi@sdu.edu.tr, +90-246-211-1269

kullanılabilmektedir. Atık malzemeler ve hafif agregaların kullanımının önemi çevresel etkileri azaltmaktır.

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Yazar Kimliği / Author ID (ORCID Number)

Serdal Terzi, 0000-0002-4776-824X

Esra Mine Buyukdogac, -

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1. Introduction

Hot mix asphalt (HMA) surface course materials consist of three phases: aggregates, asphalt binder (mastic) and air voids. Aggregates constitute the skeleton of HMA mixtures and the asphalt cement or mastic binds aggregates together. Properties of HMA mixtures are highly dependent on certain factors such as the volumetric fraction of asphalt binder, aggregate structure, air void distribution, properties of asphalt, properties of aggregates, and interfacial bonding strength between asphalt binder and aggregates [1].

Previous research studies have investigated many different natural stone and waste materials for use as aggregate or filler in HMA, for example, asphaltite, basalt, hydrated lime, recycled fine aggregate powder, waste ceramic materials, coarse recycled aggregates, recycled waste lime, cleaned oil-drill cuttings waste, marble dust and andesite [2].

For cement and building stone usage, volcanic rocks with natural zeolites are mined for more than 1000 years which are hydrated aluminosilicate minerals that contain alkaline and alkaline-earth metals. For centuries, people thought natural zeolites occurred only in small amounts inside cavities of volcanic rock. But in the 1950s and early 1960s, large zeolite deposits were discovered in volcanic tuffs in the western United States and in marine tuffs in Italy and Japan. And since then, similar deposits have been found around the world, from Hungary to Cuba to New Zealand. The discovery of these larger deposits made commercial mining of natural zeolite possible [3].

Currently, the world's annual production of natural zeolite is about 3 million metric tons. The major producers in 2010 were China (2 million metric tons or "t"), South Korea (230,000 t), Turkey (70,000 t) and United States (67,000 t). The availability of zeolite-rich rock at low cost and the shortage of competing minerals and rocks are probably the most important factors promoting its large-scale use. According to the United States Geological Survey, it is likely that a significant percentage of the material sold as zeolites in some countries is ground or sawn volcanic tuff that contains only a small amount of zeolite. Examples of such usage include dimension stone (as an altered volcanic tuff), lightweight aggregate, pozzolanic cement, and soil conditioners [4].

Areas of natural zeolite usage are often small and less associated with construction and manufacturing applications than most other industrial minerals. Consequently, the recent U.S. economic recession had only a relatively minor impact on the industry. However, construction markets outside of the United States, where natural zeolites are widely used as dimension stone, lightweight aggregate, and pozzolan were affected by the 2008–09 recession because of the reduced level of building activity. World production of zeolites remained unchanged in 2010 from that of 2009 because of the overall lack of economic growth in many regions of the globe [5].

Pumice is formed during explosive volcanic eruptions and abundantly found in Isparta region of Turkey. Turkey has seven billion cubic meters of total pumice reserves [4] in this region. Pumice is used in the fields of construction, chemicals, agriculture, dentistry, etc. Large sizes of pumice stone are mostly consumed in these application areas while smaller sizes are not often utilized. Accordingly, there is a good stock of smaller sizes of pumice stone available. The major producers in 2010 were Turkey (4100 metric tons or "t"), Italy (3000 t), Iran (1500 t), Greece (1300 t), Syria (900 t) and other countries (total 17 000 t) [6].

The samples having pumice, zeolite and limestone aggregate materials were prepared for optimum bitumen content determined following the Marshall mix design procedure, which is the current LAC mix design procedure used in Turkey. Different LAC mixes were prepared with limestone used as the coarse aggregate and pumice and zeolite used as fine aggregate and with limestone used as the fine aggregate and pumice and zeolite used as coarse aggregate.

2. Materials and Methods

In this section, information is given about the materials used in asphalt mixtures, i.e., the mostly crushed limestone, pumice, zeolite and the asphalt binders.

2.1. Materials

Zeolite and pumice waste obtained from different areas in Turkey were used in highway construction. The aggregate material properties used in this study are given in Table 1. The aggregate grading curves for asphalt mixtures were obtained from Turkish Highway Directorate specifications. To prepare the Marshall samples, 50/70 and 160/220 penetration asphalt cements were used. Table 1 shows the properties of the limestone, zeolite and pumice aggregate materials. As listed in Table 1, Abrasion Loss (Los Angeles) values of zeolite and pumice aggregates are greater than those of the limestone aggregates because of their porous structure. Scanning Electron Microscopy (SEM) images of the limestone, zeolite and pumice samples were also taken (see Figure 1).
Because of both zeolit and pumice aggregates have a lot of voids (Figure 1 b), asphalt mixtures could not be prepared without additive materials. Liquid Anti-strip (LAS) Additives was used for preparation of the mixtures. Table 2 lists the used LAS properties.

For this paper, a liquid anti-strip was used and the dosage was optimized. Different LAS amounts (0.4, 0.5, 0.6, 0.8, 0.9, 1.0 and 1.1 %) were used to determine the optimum LAS content for the mixtures.

Table 2. Liquid Anti-strip Additives (LAS) Properties [10]

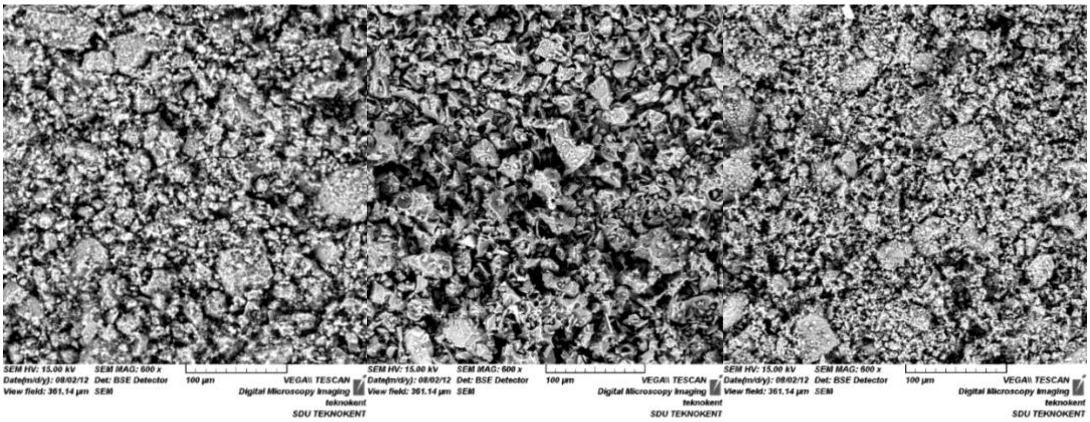
Viscosity	250-500
Specific Gravity	1.02+-0.04
Weight, kg/m^3	1.01 ± 0.04
Flash Point (ASTM D92)	>120C
Pour Point (ASTM D97)	12C/54F

2.2. Marshall Stability Test

The Marshall mix design procedure was followed to determine the optimum percentage of asphalt binder. Laboratory Marshall samples were prepared using the same aggregate gradation at 4%, 5%, 6%, 7% and 8% asphalt contents. Because of the obtain to workability, high asphalt contents (9, 10 and 11 %) were used for pumice and zeolite aggregates The samples having zeolite, pumice and limestone aggregates were prepared and the optimum asphalt contents were then determined by the Marshall Stability Test procedure.

Table 1. Properties of aggregate materials used in HMA mixtures

Type	Properties	Standard	Limestone	Zeolite	Pumice
Fine Aggregate	Specific gravity (g/cm^3)	(ASTM C 127-88, 1992)	2.660	1.81	1.77
	Saturated specific gravity		2.652	23.5	18.82
	Water Absorption (%)		0.130	21.123	15.525
Coarse Aggregate	Specific gravity (g/cm^3)	(ASTM C 128-88, 1992)	2.329	1.22	1.70
	Saturated specific gravity		2.428	45.2	28.67
	Water Absorption (%)		2.800	46.8	42.4
	Abrasion Loss (%) (Los Angeles)	ASTM C 131(1996)	20.38	87.45	37.33



(a) (b) (c)

Figure 1. SEM analysis results of limestone (a), zeolite (b) and pumice (c) samples.

3. Results

3.1. Pure mineral aggregate test results

In this study, optimum asphalt contents, optimum additive ratios (0.6, 0.8, 0.9 and 1%) and asphalt binder types (50/70 and 160/220) were determined for each aggregate type (limestone, zeolite and pumice).

The optimum asphalt contents were determined for the different mix designs by taking average value of the following three asphalt contents according to the following:

1. Asphalt content corresponding to the maximum stability;
2. Asphalt content corresponding to the maximum bulk specific gravity;
3. Asphalt content corresponding to the median of designed limits of percent air voids in the total mix (i.e. 4%); and
4. Asphalt content corresponding to the median of designed limits of percent voids filled with bitumen in the total mix (i.e. 80%).

As given in Table 3, optimum asphalt content does not meet the specification limit for both zeolite and pumice aggregate mixtures. Also, these contents increase the cost. In addition to this, zeolite and pumice can be used as mineral aggregates for asphalt concrete mixtures as Marshall stability and flow (Type 3). But, limestone aggregate has higher Marshall Stability values than others. All aggregate types resulted in adequate asphalt mix flow properties. Limestone and pumice aggregate mixtures have 0.8% LAS additive content, while zeolite has 0.6 %.

As a result, pure zeolite and pumice aggregates mixtures does not meet the optimum asphalt content specification (above 8 %). For this reason, limestone was used as the coarse aggregate (retained on No. 4 sieve) and zeolite and pumice wastes mixtures as the fine aggregate (passing No. 4 sieve) and alternatively, limestone was used as the fine aggregate and pumice and zeolite were used as the coarse aggregate to prepare mixtures and test them for their Marshall stability values. As indicated in Figure 2, all mixtures meet to stability specification but do not meet to the flow limit.

Table 3. Physical Properties of Mixtures

	Specification Limits [16]	**Limestone**	**Zeolite**	**Pumice**
Optimum asphalt content (%)	5-8	5.4	**9.75**	**10.5**
Bitumen type	-	160/220	160/220	50/70
Additive content	-	0.8 %	0.6%	0.8%
Maximum stability (kg)	Min. 400	1723	995	785
Flow (mm)	2-4	3.74	3.59	3.94

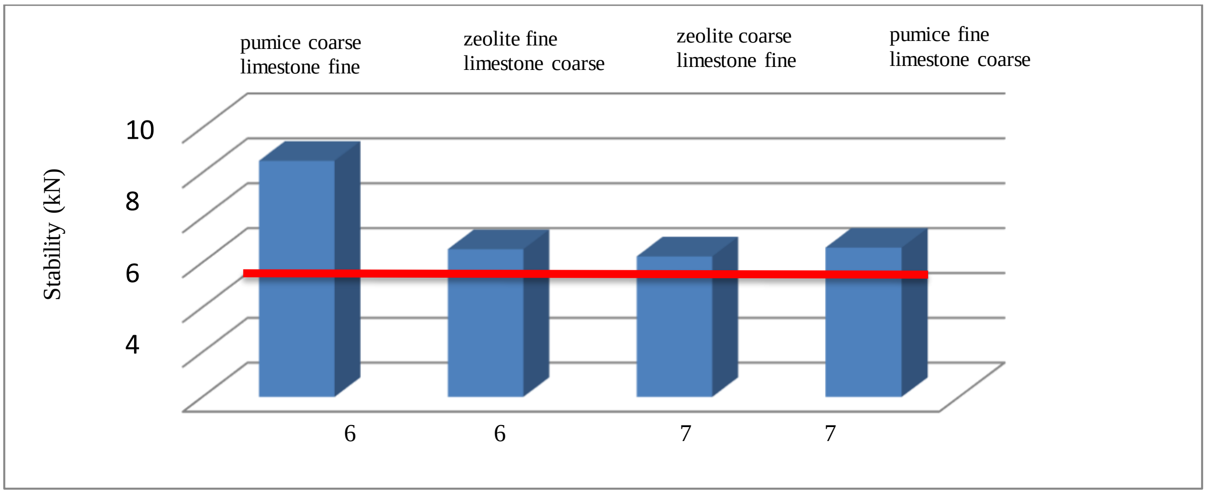


Figure 2. Marshall stability values obtained for different asphalt contents

3.2. Mineral filler ratio test results

As the third stage of this research, the usability of zeolite and pumice wastes was investigated as mineral filler in asphalt mixtures at optimum asphalt content. As shown in Figure 3 optimum mineral filler contents were obtained as 6 % in order to meet the specification. Limestone mineral filler mixtures have the best stability value (see Figure 3).

3.3. Indirect tensile (IDT) strength test

One of the commonly used properties to evaluate asphalt mixtures is the tensile strength, which is used to quantify the effects of moisture and determine the fracture resistance of an asphalt mixture. Typically, the tensile strength can accurately be determined from an Indirect Tension Test (IDT) for the strength in accordance with AASHTO TP9-02 [14].

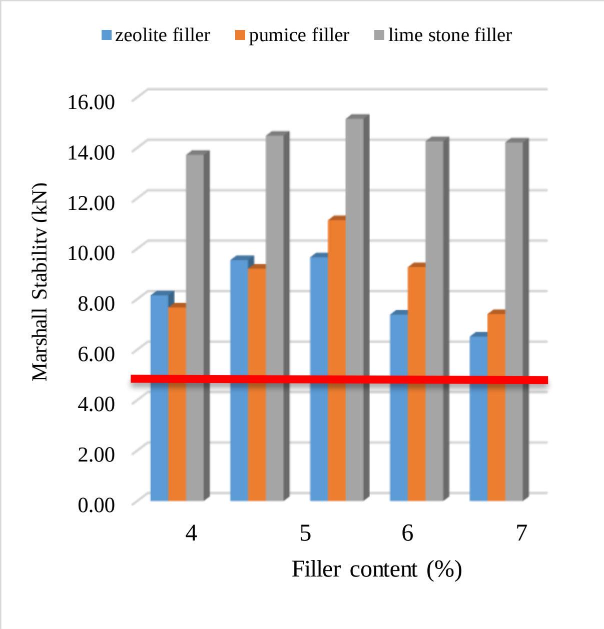
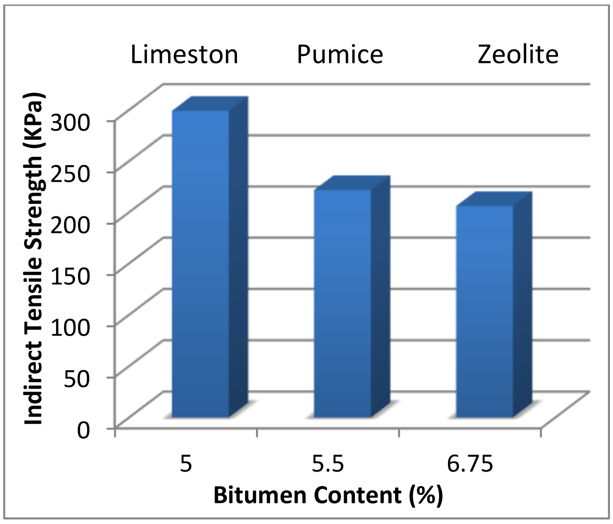


Figure 3. Relationship of stability and mineral filler ratio

The IDT is a straightforward strength test that allows the use of currently available equipment in most laboratories, being Marshall Stability machine and a water bath set at 45 ºC.

IDT Strength test was carried out in order to assess limestone, pumice and zeolite mineral filler sample, which was the sample with the best results. Optimum asphalt contents were determined for limestone filler (5%), pumice filler (5.5 %) and zeolite filler (6.75%).

In view of IDT strength, limestone mineral filler asphalt mixtures had higher strength properties than the other samples (Figure 4)



4. Conclusions

In this study, the zeolite and pumice wastes were investigated for their potential use as aggregates in lightweight asphalt mixtures. First of zeolite and pumice stone and limestone samples were prepared for the target engineered gradation. Following the Marshall mix design procedure, stability tests were performed to determine the optimum asphalt percentages. Samples with different aggregate materials had the following optimum asphalt contents: limestone aggregate 5.4%, zeolite stone aggregate 9.75% and pumice stone aggregate 10.5 %.

The Marshall stability test results were determined for the limestone coarse aggregate and pumice and zeolite fine aggregate combination as well as the limestone used as the fine aggregate and pumice and zeolite used as coarse aggregate alternative with the asphalt contents varying from 4% to 8%. The pumice coarse aggregate and limestone fine aggregate combination gave higher stability results than the other mixtures.

All mixtures met the Turkish Highway Specification Type 3 requirements. This type of pavement has a thinly surfaced layer for high friction demand, needs to prevent water infiltration and as serve as an overlay with 25-30 mm above old pavement with a maximum of 6 mm rutting allowed.

This study had demonstrated that especially in areas with wide spread zeolite and pumice waste, if transportation costs do not exceed the cost of limestone, these waste materials can be used as fine mineral aggregate or mineral filler in place of limestone in asphalt concrete mixtures. Because these waste materials have very low weights, they can be used in the wearing course in paved parking areas and non-heavy weight vehicle traffic roads.

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Conflict of Interest

No conflict of interest was declared by the authors.

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