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The Effects of Animal Bone Ash on Asphalt Pavement Mixtures

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Abstract

This study focuses on alternative raw material sources to meet the demand for sustainable construction materials. Particularly, it is suggested that waste materials, such as animal by-products, could provide a solution for enhancing the mechanical properties and durability of asphalt concrete. The research aims to improve the physical and mechanical properties of asphalt concrete by utilizing bone ash obtained from Category 3 animal by-products through a hydrolysis procedure. Experiments conducted showed that the addition of 5% bone ash ensured maximum stability when used in conjunction with different percentages of bitumen. Overall, some positive developments were observed in the physical and mechanical properties of asphalt concrete containing animal bone ash, possibly due to strengthening the bond between aggregate particles and bitumen material. This study highlights the potential of animal bone ash in improving the mechanical properties of asphalt concrete and recommends a 5% bone ash addition for optimum stability and durability. However, further research and field tests are needed to better understand the long-term effects of animal bone ash and its performance under different road conditions.

Keywords: Sustainable construction materials, Asphalt concrete, Mechanical properties, Animal bone ash, Stability.

1. Introductions

With the rapidly growing world economy and expanding population, the need for new roads is expanding day by day. To meet this increasing demand, asphalt is the globally preferred road superstructure type. Asphalt can be applied both hot and cold and can withstand a variety of weather conditions. Hot asphalt mixtures are mixtures in which bitumen is used at high temperatures and are generally recommended for use on roads with heavy traffic. Cold mixtures are mixtures that can be used at low temperatures and are used on roads where there is little traffic and maintenance. Today, 92% of freight transportation and 95% of passenger transportation takes place on highways. Thus, the traffic capacity of 20 years ago has increased at least 5 times, and the axle weight, which is the basis of superstructure projects, has increased from 8 tons to 13 tons. This situation has led to the deterioration of asphalt concrete in a shorter time than the expected service life. The concept of deterioration in asphalt concrete is defined as the degree to which the expected serviceability decreases as a result of traffic loads and environmental interactions at the end of the design life of a pavement structure, and it has been emphasized that the explanation of serviceability concept and a more detailed examination of the subject are necessary [1].

Furthermore, environmental issues and their solutions have been prioritized in research and studies conducted in the transportation sector. In this regard, research and studies began in the late 1950s [2]. Since the mid-1990s, various techniques have been investigated to reduce the energy consumption involved in the production of hot mix asphalt, which is particularly renowned for its high mixing and compaction temperatures. In addition, the increase in living standards, social development, inadequacy of existing resources, and rising material and energy costs have prompted highway engineers to explore alternatives for constructing new roads and improving existing ones [3]. A satisfactory superstructure design should be durable, resistant to permanent deformation, cost-effective, and environmentally friendly.

Recently, there has been an increasing demand for an asphalt mixture capable of withstanding various external loads and minimizing cracking. The designed lifespan of infrastructures typically spans around 20 years, considering anticipated traffic loads. In determining the thickness of the superstructure, the repetition of axle loads is a significant factor, and an increase in the repetition of heavy axle loads decreases the service life of the road. Under these conditions, thicker superstructures and higher costs have been required to achieve the same service life [4]. For this reason, the superstructure that provides the best stability should exhibit resistance against deformation and formation of wheel tracks under traffic loads. Neither excessively high nor low stability is desirable. High stability leads to asphalt cracking, while low stability results in wheel track depressions in the asphalt. Therefore, the aim is to achieve maximum stability at the optimum asphalt percentage [5].

Thom and Elliott (2009) stated that with the high modulus of hardness of asphalt, it is possible to obtain a pavement that can withstand high traffic loads without cracking [6]. Previous researchers such as Zaumanis and Mallick (2014) have confirmed that the use of waste or by-product materials instead of coarse or fine aggregates and even filler materials provides a promising improvement in the mechanical properties and durability of asphalt concrete [7]. Yan et al. (2013) concluded that the filler material has a significant impact on the lifespan of asphalt mixtures due to its high influence on strength, as well as its ability to increase resistance to water penetration and improve asphalt viscosity. Therefore, as highlighted by Muniandy et al., the properties of filler materials are crucial in asphalt mixture design both physically and chemically [8]. Furthermore, recent increases in demand for construction materials, particularly in road construction, alongside the inadequacy of existing resources, have prompted a search for alternatives such as the utilization of waste materials.

In addition, in recent years, the amount of solid waste generated has increased worldwide due to the growing population, leading to the consumption of natural resources. Over the next five years, a significant increase in solid waste production is expected, which is anticipated to contribute to various environmental issues. From municipalities providing solid waste services in Turkey, it has been determined that a total of 25.28 million tons of solid waste was collected, with 12.75 million tons in the summer season and 12.53 million tons in the winter season in 2006. The use of waste materials in infrastructure can reduce the consumption of traditional highway materials and consequently decrease the extraction and processing costs of these materials. Some researchers suggest using by-product materials in replacing subbase layer materials to utilize more waste materials, while other studies oppose this view due to transportation costs and the evaluation of waste materials, advocating the significance of using these materials in asphalt applications [9]. Many researchers are interested in the use of waste materials instead of traditional materials in construction. Studies where waste materials are used in concrete or asphalt mixtures have generally shown improvements in the durability and mechanical properties of hardened construction materials.

Bindu et al. (2020) investigated the potential use of cashew nut shell (CNS) ash in asphalt mixtures. Various amounts of ash were used as a partial substitute for the fine sand component in asphalt concrete. The Marshall test was employed to determine the mechanical properties of the mixtures. The findings indicate that cashew nut shell ash can be used in asphalt concrete instead of fine sand up to 15% [10].

On the other hand, Sung et al. (2008) focused on the use of recycled waste lime instead of filler in asphalt mixtures. The results of this study demonstrate a significant improvement in stripping resistance and permanent deformation resistance at high temperatures [11]. The effect of coal waste dust as a filler in hot mix asphalt was investigated by Modarres and Rahmanzadeh (2014). Compared to the reference mixture, asphalt samples containing coal waste ash resulted in better stability and flexibility modulus [12].

Al-Busaltan (2016) selected two filler materials, namely Silica Fume (SF) and Rice Husk Ash (RHA), for up to 30% filler substitution. The results showed that Hot Mix Asphalt (HMA) design with less than 15% SF or 27.5% RHA met the requirements of local specifications. [13]. Furthermore, Tahami et al. (2018) reported that asphalt mixtures containing rice husk ash (RHA) and palm kernel ash (PKA) fillers showed higher stability and stiffness modulus compared to the control mixture. Moreover, the utilization of biomass ash has increased the thermal stability of the mixtures and enhanced the adhesive strength between asphalt and aggregates, leading to an increase in rut resistance and fatigue life of Hot Mix Asphalt (HMA) mixtures [14].

Furthermore, Sharma et al. (2010) and Choi et al. (2014) have demonstrated that fly ash can be used as a filler material in asphalt mixtures instead of filler [15-16]. Choudhary et al. (2018) investigated the effect of seven different waste materials, including glass ash, limestone ash, red mud, rice husk ash, brick dust, carbide lime, and copper waste, on bituminous mixture [17]. Waste filler bitumen mixtures have been tested for a range of mechanical properties compared to cement filler bitumen mixtures, including strength and resistance to moisture, wheel tracking, and cracking. The results have shown that the properties of waste filler mixtures are satisfactory and superior to traditional fillers. Waste mineral products (marble, granite, and steel slag) have been proposed as alternatives to conventional filler materials by Tarbay et al. (2018) [18].

Additionally, rice husk ash has been investigated as a waste filler material in hot asphalt mixtures by Sargin et al. (2013) [19]. In the asphalt concrete mixture, four rates of limestone have been used as traditional fillers (4%, 5%, 6%, and 7%). According to the Marshall Stability test, the highest stability was achieved using 5% filler. Rice husk ash has been used as a substitute for limestone filler at rates of 25%, 50%, 75%, and 100%. From the results, it can be observed that a mixture containing 50% limestone filler and 50% rice husk ash exhibits the highest stability compared to other percentages and control samples.

As a result of the study in which granular polymers and waste plastics were used as additives in asphalt concrete, it was determined that asphalt concrete produced with polymer additives in different configurations and ratios was more durable than traditional concrete [20].

Studies conducted over the past three decades regarding the use of polymers as additives in asphalt concrete and the results of these studies have been summarized by Y. Yıldırım (2005) [21]. In the study conducted by Navarro et al. (2004) it was observed that the addition of ground rubber tires to asphalt concrete improved the temperature-dependent properties of the asphalt concrete [22]. On the other hand, in this study, which serves as an example of polymer enhancement, it has also been demonstrated that the addition of rubber has positive effects on the long-term aging properties of asphalt concrete [23]. There is diversity observed in the methods used for evaluating the results of research conducted on asphalt concrete incorporating waste tires. Ground rubber and polymers have been added to asphalt mixtures, and improvement studies using rubber have yielded positive results compared to normal asphalt concrete in terms of permanent deformation, wheel tracking, and low-temperature cracking [24].

Improvement studies have been conducted regarding the incorporation of various thermoplastic polymers, namely SBS, SEBS, EVA, and EBA, into asphalt. At the conclusion of the study, it was observed that different polymers exhibited varied effects on asphalt properties, particularly enhancing storage stability, creep resistance, and temperature-dependent characteristics [25, 26].

The modernization and intensified management of livestock farms, which have experienced rapid development in recent years, have brought forth numerous challenges. Concurrently, the accumulation of waste, holding significant economic potential, has emerged as a pivotal environmental concern amidst the rising livestock population. Substantial quantities of animal bones, such as those from cattle, have been generated, occasionally leading to complications in waste disposal procedures. Considering that approximately 15% of beef carcasses and 16% of lamb carcasses contain bones, the average solid waste output from a beef slaughterhouse is estimated at 275 kg per tonne of total live weight slaughtered, equating to 27.5% of the animal's weight [27].

As stated by Muhammed et al. (2012), following the incineration process, animal bones primarily consist of approximately 80% calcium and magnesium, with approximately 10% carbon and other substances [28]. Ali et al. (2019) utilized traditional and dynamic rheometer test methods to investigate the effects of Portland cement and waste animal bone additions on the asphalt binder properties. Increases in the additive content resulted in decreased penetration, increased softening point, and increased flash point, indicating enhanced stiffness and resistance to wheel tracking. Consequently, animal bone ash may possess some pozzolanic properties in hot asphalt mixtures [29].

While bitumen constitutes 5-7% by weight and approximately 15% by volume of the asphalt mixture, its performance significantly influences the overall performance of the road throughout its service life [30]. Thus, enhancing the performance of flexible pavements is directly linked to the quality of the bitumen utilized in the mixture [31]. The performance of bitumen can be enhanced through the addition of certain percentages of additives, which may include various commercial, natural, artificial, and industrial substances. Although this initially raises the construction costs of flexible pavements, it ultimately yields economic benefits by reducing maintenance and repair expenses over the road's service life, provided that a high-quality application is achieved [32].

This study investigates the use of animal bone ash as an adjunct to conventional filler material in hot mix asphalt, aiming to evaluate its impact on asphalt pavement performance.

2. Test Methods

2.1. Marshall Stability Test

Utilizing standardized testing methods such as TS EN 3720/12697, AASHTO T 245, and ASTM D 1559, the Marshall test serves as a laboratory procedure employed to assess the technical properties of asphalt mixtures. Developed specifically for determining the durability and performance of asphalt mixes utilized in highway construction, the Marshall test evaluates the flow characteristics of the asphalt mixture at elevated temperatures, thus gauging the material's resistance to deformation under high temperatures. Accurate determination of asphalt flow properties, subjected to factors such as vehicular traffic and intense solar radiation, enables more precise performance predictions. Additionally, the Marshall test measures the stability of the asphalt mixture, indicating how the material will behave under the influence of gravity and high temperatures. This parameter reflects the strength and load-bearing capacity of the mixture, with higher stability values suggesting greater strength and durability. The Marshall test aids engineers in determining the optimal mix design by assessing the performance of various asphalt mix compositions, allowing for the optimization of the mix's composition and properties to achieve the best performance under specific road, traffic, or climatic conditions. Integral to the quality control and assurance processes of asphalt manufacturers and construction firms, Marshall testing ensures the adherence of asphalt produced to specified standards, facilitating the use of materials that meet quality criteria for long-lasting and dependable infrastructure.

2.1.1 Marshall stability test procedure

In an oven set to 160°C, a pre-determined aggregate sample weighing 1150 grams is left for one day (24 hours), while the bitumen is allowed to rest for 2-3 hours. Throughout the experiment, the molds, mixing sticks, shovels, and aggregate containers to be used must be kept in the 160°C oven to prevent any heat loss during the test. After removing the aggregate mixture from the oven, it is transferred to a mixer bowl, and a well is formed in the center to pour the bitumen into. A specific amount of bitumen, determined as a percentage of the aggregate weight at 3.5%, 4%, 4.5%, 5%, 5.5%, 6%, and 6.5%, is poured onto the aggregate as per the predetermined proportions. For each specified amount of bitumen, a total of 21 (3x7) samples are prepared, with three samples per designated bitumen percentage. The aggregate and bitumen are mixed in the mixer for 1.5-2 minutes. During this process, the mixer bowl is placed on the mixer heating device to prevent a drop in the mixture's temperature. Similarly, to prevent heat loss, the mixer head should be kept in the oven and utilized during mixing. As the mixing process nears completion, molds are removed from the oven and greased with Vaseline or a similar substance to prevent sticking. Greased or impermeable paper cut to suitable sizes is placed at the bottom of the mold. The mixture is scooped from the mixer, poured into the mold, and compacted using a tamper. The temperature of the mixture is measured at this stage, and greased or impermeable paper is placed on top of the mixture again. The temperature of the mixture should not drop below 140°C at this point. The mold containing the sample is placed on a Marshall hammer, and 75 blows are applied to each side for Hot Mix Asphalt (HMA) or 50 blows for Stone Mastic Asphalt (SMA). Care should be taken during compaction to ensure that there is no material loss from the sample. The mold is then placed on a clean, flat surface to allow the sample to cool. The papers on the top and bottom surfaces of the sample should be removed before the sample cools to prevent them from sticking. The molds are left to cool for approximately 3 hours. After cooling, the samples are removed from the molds using a jack, labeled, and marked. The samples are left for one day at room temperature. The next day, if there are any protrusions around the samples, they are cleaned. Height measurements are taken from the samples using a caliper. Measurements should be taken from approximately 120°C apart at three different points on the sample. The weights of the samples in air and water are measured and recorded. The samples are left in a water bath at 60°C for 30 minutes. After being removed from the water bath, the samples are dried and placed in the Marshall strength device. The device is operated, applying a load to the sample at a speed of 51 mm/minute. As a result, flow and strength values of the sample are obtained. The results obtained from applying all the previous steps to all samples, including height, weight in air and water, Marshall flow and strength values, are arranged in table format. Flow and strength values for samples are multiplied by correction factors based on their heights and added to the table. The purpose of using Marshall correction factors is to ensure the evaluation of samples with different heights under the same conditions. Three samples were prepared for each bitumen ratio, and the conformity of the results obtained from these samples is checked by plotting a "Bitumen Ratio (%)- Air Void (%) " graph. If the results on the graph are close to each other, it is accepted that the test results are consistent and compatible, and the calculations continue. Based on the results obtained from the prepared Marshall Table, "Bitumen ratio Practical specific gravity", "Bitumen ratio-Marshall strength", "Bitumen ratio-air void ratio", and "Bitumen ratio-Void filled with bitumen ratio" graphs are drawn. According to these graphs, the bitumen ratio corresponding to the maximum practical specific gravity value, the bitumen ratio corresponding to the maximum Marshall strength value, the bitumen ratio corresponding to the 4% air void ratio value (mean of lower and upper air void level for wearing course), and the bitumen ratio corresponding to the 70% void filled with bitumen ratio value are determined. The average of these four bitumen ratios is calculated to find the optimum bitumen ratio for the mixture. To determine whether the found optimum bitumen ratio falls within the specification limits, a "Bitumen Ratio-Flow" graph is plotted. The optimum bitumen ratio is accepted if it meets the flow limit.

2.2. Modified Lottman Test (AASHTO T-283)

One of the most important studies conducted to determine the usability of Hot Mix Asphalt (HMA) in road pavement is the measurement of the mixture's sensitivity to water. The AASHTO T-283 test is widely used to determine the sensitivity of compacted HMA to the effects of water. Developed by Lottman in the 1970s, the test conditions were modified and standardized by AASHTO. The test is aimed at determining the strength loss of the mixture due to water. The results obtained are used to determine the sensitivity of hot mixtures to stripping in long-term service processes on roads [33, 34, 35]. Compacted asphalt samples are divided into two groups: dry and conditioned (wet), and subjected to the indirect tensile test to determine the mixture's strength loss. The reason for obtaining the indirect tensile strength of the mixture is that it is one of the most important parameters for the continuity of hot mix wearing layers, as the tensile strength of the hot mix is critical for resisting the tensile stresses caused by traffic and environmental effects. If this strength is low, the mixture may deteriorate due to the tensile stresses generated by traffic and environmental factors At the conclusion of the study, it was observed that different polymers exhibited varied effects on asphalt properties, particularly enhancing storage stability, creep resistance, and temperature-dependent characteristics [36]. For each test group to be subjected to the test, at least 6 samples are prepared, consisting of 3 unconditioned and 3 conditioned specimens. The prepared uncompacted mixture samples are placed in trays and cooled at room temperature for 2 hours, then placed in an oven at 60°C for 16 hours. The mixture samples, which are allowed to stand for 2 hours at the compaction temperature, are compacted at 6–8% air voids and left at room temperature for 24 hours. Dry specimens not subjected to conditioning are soaked in a water bath at 25°C for 2 hours and then subjected to the indirect tensile test to failure. For the conditioned specimens, a vacuum is applied with a manometer for 5–10 minutes at 13–67 kPa suction pressure to saturate them with 70–80% water content. The saturated specimens are placed in a freezer at -18°C for 16 hours. After removal from the freezer, the specimens are placed in a water bath at 60°C for 24 hours, then removed and placed in a water bath at 25°C for 2 hours before being subjected to the indirect tensile test. The ratio of the indirect tensile strength of the conditioned specimens (ITSwet) to that of the unconditioned specimens (ITSdry) is calculated using the following equation:

$$ITSR = (ITS_{WET}/ITS_{DRY})x100 \tag{1}$$

ITSR Indirect tensile strength ratio (%),
ITS_{wet}: Average indirect tensile strength (kPa) of the conditioned (wet) group,

ITS_{dry}: Average indirect tensile strength (kPa) of the unconditioned (dry) group.

According to the Superpave mixture design method, for HMA to be deemed sufficiently resistant to water effects, the ITSR (Indirect Tensile Strength Ratio) value should be at least 80% [37, 38]. However, in the original Lottman method, it is considered sufficient for this value to be at least 70%. Hot mixtures with an ITSR value lower than 80% in the test are generally deemed to lack sufficient resistance to water effects, and measures are taken to enhance the mixture's water resistance. Typically, anti-stripping additives are added to increase the mixture's resistance to water effects. For modified mixtures using additives, the ITSR value is expected to be at least 85% [35, 37].

2.3 Materials

Typically, for hot asphalt mixtures, a composition of approximately 95% aggregate, 5% bitumen, and additives is used. In this study, filler and animal bone ash were utilized as aggregate, bitumen, and additive, respectively.

2.3.1 Bitumen

The bitumen used for this research was sourced from Compañía Española de Petróleos, S.A.U. The test results of the bitumen are indicated in Table 1.

2.3.2. Aggregates

The aggregate used in the research was supplied by CONTEC- Construções e Engenharia, S.A. The gradation values of the aggregate are shown in Fig. 1, while the physical properties of the aggregates and specification requirements are presented in Table 2.

Table 1. Bitumen test results

				SPATICIFATIONS LIMITS	
TESTS	UNIT	NORM	RESULTS	MIN	MAX
Penetration (25 ºC; 100g; 5s)	0.1mm	EN 1426	39	35	50
Penetration index	-	EN12591	0,1	-1.5	0.7
Softening temperature	ºC	EN1427	54	50	58
Fraass brittleness temperature	ºC	EN12593	-1	-	-5
Resolution	%	EN 12592	130	99	-
Ignition temperature	ºC	EN2592	280	240	-
Resistance to ageing at 163 ºC (EN 12607-1)					
Mass change	%	EN 12607-1	0.2	-	0.5
Retained penetration (25 ºC; 100g; 5s)	%	EN 1426	62	53	-

Table 2. Physical properties of aggregates and specification requirements

Property	Standard	Units	Gneiss 8/20	Gneiss 4/22	Sand 0/4	Filler	Limit
Flakiness index (FI)	EN 933-3 (34)	%	FI_{15}	FI_{16}	…..	…..	FI_{20}
Resistance to fragmentation: Los angeles (LA)	EN 1097-2 (35)	%	LA_{20}	LA_{21}	…..	…..	LA_{30}
Resitance to wear: micro-Deval (M_{08})	EN 1097-1 (36)	%	M_{08} 10	M_{08} 10	…..	…..	M_{08} 15
Polished stone value (PSV)	EN 1097-8 (37)	%	PSV_{30}	PSV_{30}	…..	…..	PSV_{30}
Water absorption (WA)	EN 1097-6 (38)	%	0.5	0.6	0.6	…..	WA_{24}1
Assessment of fines: methylene blue (MBr)	EN 933-9(39)	g/kg	…..	…..	MBr10	MBr10	MBr10
Voids of dry compacted filler(V)	EN 1097-4 (40)	&	…..	…..	…..	32	$V_{24/34}$
Delta ring and ball (ºC)	EN 13179-1 (41)	ºC	…..	…..	…..	14	….

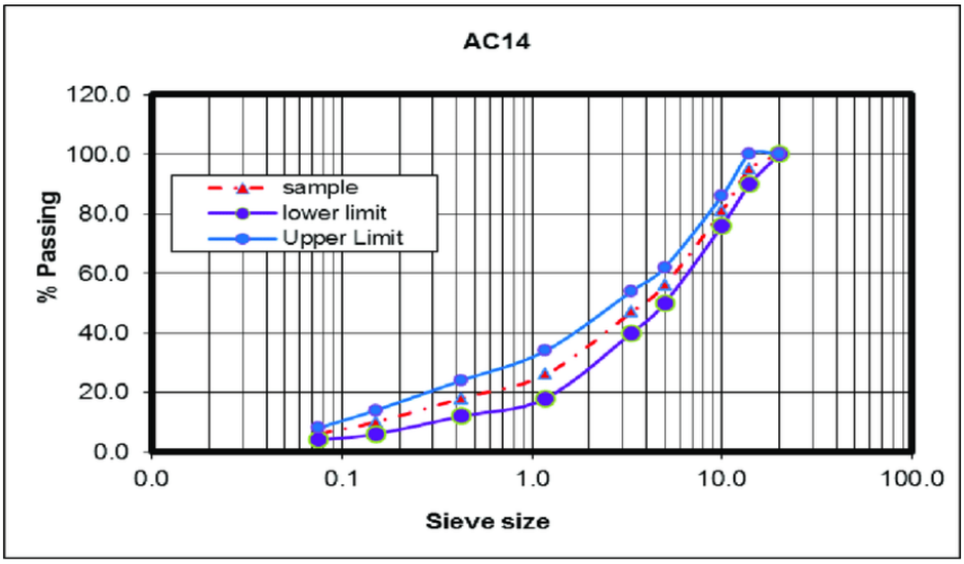

Fig. 1. Grading of the aggregate's mixture and specification limits

2.3.3 Animal bone

The bone used in the study was sourced from Sebol - Comércio e Indústria de Sebo, S.A. Bone meal is a product obtained from the hydrolysis procedure of Category 3 animal by-products selected in compliance with Regulation 1292/EC. This regulation dates back to August 5, 2005. Tri-calcium phosphate derived from animal bones is recognized as a feed product under Article 11.3.4 of Regulation (EC) No 2017/1017 dated June 15.

The hydrolysis procedure is the process whereby the chemical bonds of a substance are broken or decomposed through the action of water. In this process, water molecules break the chemical bonds between the components, thereby breaking the molecules into smaller parts. The hydrolysis procedure in animal bones is predominantly a chemical process that occurs under specific temperature and pressure conditions. This process is typically conducted using a solution or reagent that acts as a hydrogen donor.

During this process, the organic components within the bones are decomposed by the action of water under high temperature and pressure. In this decomposition process, proteins can be converted into amino acids, fats into free fatty acids, and minerals into more soluble forms. Consequently, the product obtained as a result of hydrolysis becomes more digestible and easier to process.

The aim of the study is to investigate the changes in the mechanical and physical properties of the mixture with the use of animal bone ash. For this purpose, animal bone ash was used in each sample up to 5% of the bitumen content. The properties of bone meal are specified in Table 3.

Table 3. Physical and chemical properties of animal bone

FORM	Colour	Odor	Density
Ash	White to gray	Typical	0.80 Kg/m^3
CONSERVATION			PACKAGING
In cool and dry conditions			Big Bags (0.8 ton)
REFERENCE PARAMETERS			
DESGINATION	UNIT	VALUE	REFERENCE
Crude protein	%	±9	Internal quality criteria
Ash	%	±84	
Moisture	%	±3	
Calcium	%	±28	
Phosphorous	%	±14	
Ash unsoluble in HCI	%	±1	
Phosphorous unsoluble in citric acid 2%	%	±7	

3. Experimental Studies

3.1. Marshall Test Results

Marshall test results for Hot Mix Asphalt (HMA) mixtures containing 5% animal bone ash used in conjunction with bitumen are depicted in Fig. 2., 3., 4., 5., 6.,7. and 8., showing the volumetric specific gravity (Dp, g/cm3), maximum theoretical specific gravity (Dt, g/cm3), air voids (Vh, %), voids in mineral aggregates (VMA, %), voids filled with bitumen (VFA, %), stability, and flow values, respectively.

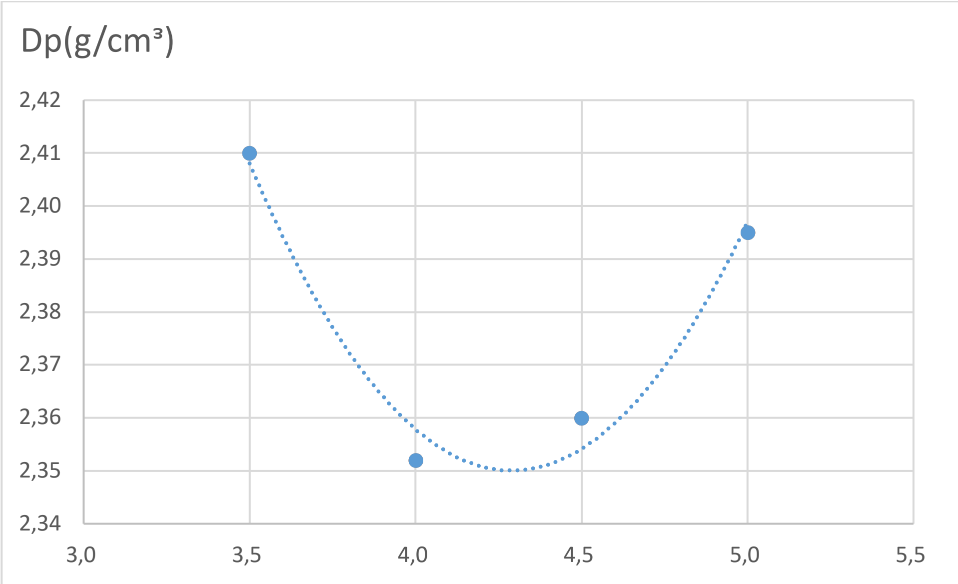

Fig. 2. Volume specific gravity

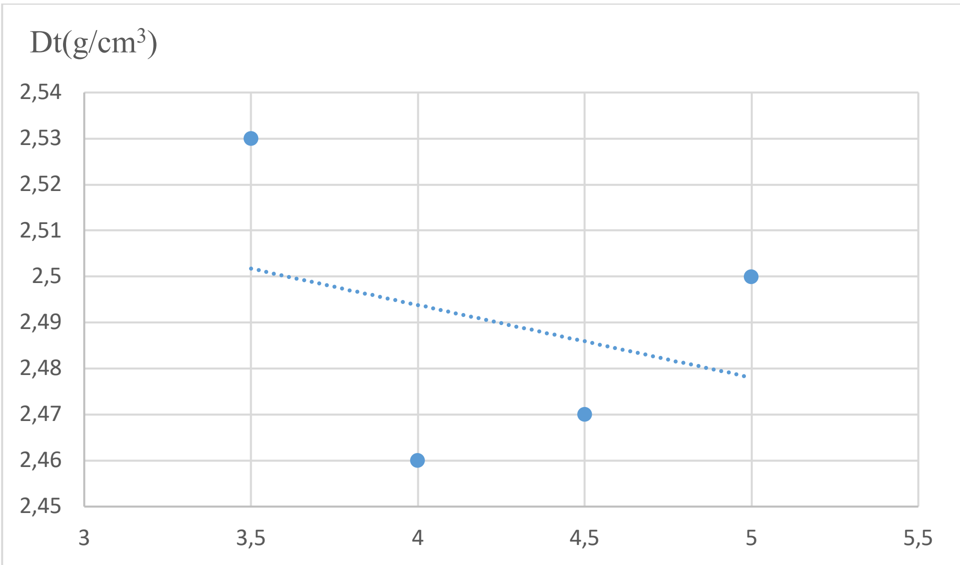

Fig. 3. Maximum theoretical specific gravity

As seen in Fig. 2. and 3., the volumetric specific gravity and maximum theoretical specific gravity values of hot mix asphalt samples prepared with four different percentages of bitumen and containing 5% animal bone ash exhibit a decrease from 4% to 3.5% bitumen addition, while an increase is observed at 4.5% and 5% bitumen additions.

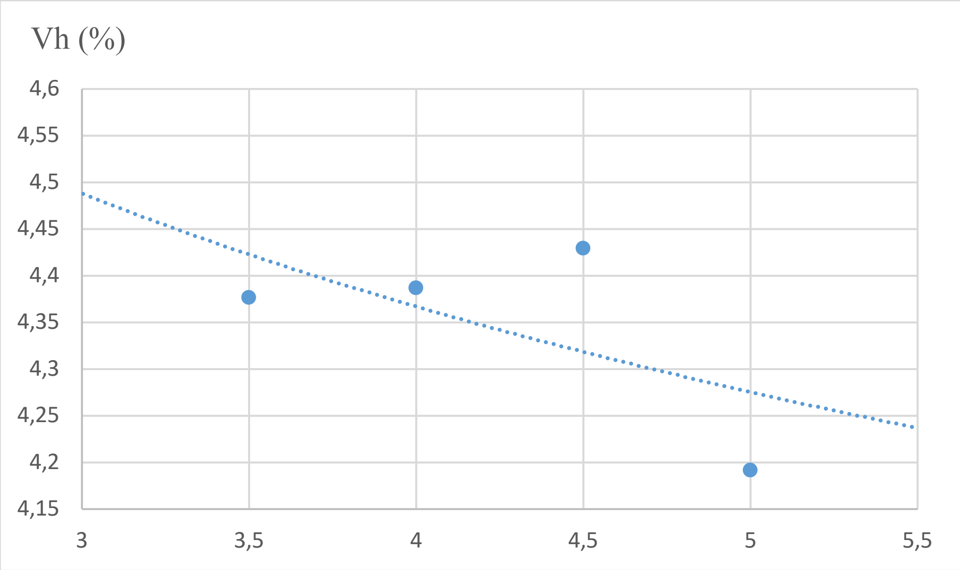

Fig. 4. Air void percentage

Fig. 4. shows that the highest air void content is observed at 4.5% bitumen addition, while the lowest air void content is observed at 5% bitumen addition. All prepared HMA samples remained within the specified limits of the KGM specification.

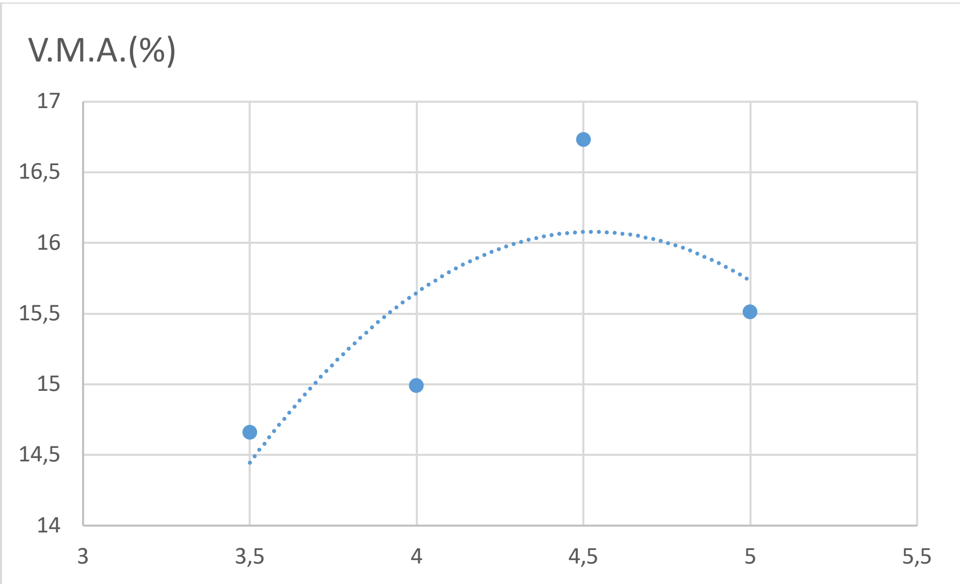

Fig. 5. Percentage of voids between aggregates

Fig. 5. indicates that the inter-aggregate void value increased compared to 3.5% bitumen addition at 4% bitumen addition, while it decreased compared to 4.5% and 5% bitumen additions. Each HMA mixture containing 5% animal bone ash remained above the minimum specified inter-aggregate void percentage in the KGM specification.

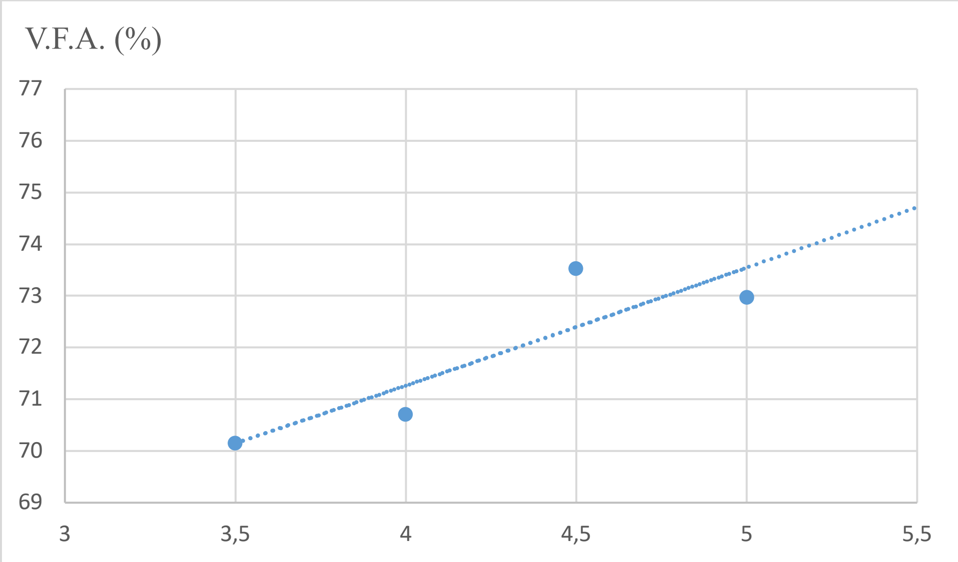

Fig. 6. Aggregate filled void percentage

Fig. 6. shows that the inter-aggregate filled void ratio has the highest percentage at 4.5% bitumen addition, while it has the lowest percentage at 3.5% bitumen addition. The HMA mixture prepared with 4% bitumen addition has a lower aggregate filled void ratio than the HMA mixture prepared with 5% bitumen addition. Each HMA mixture remained within the specified limit values in the KGM specification.

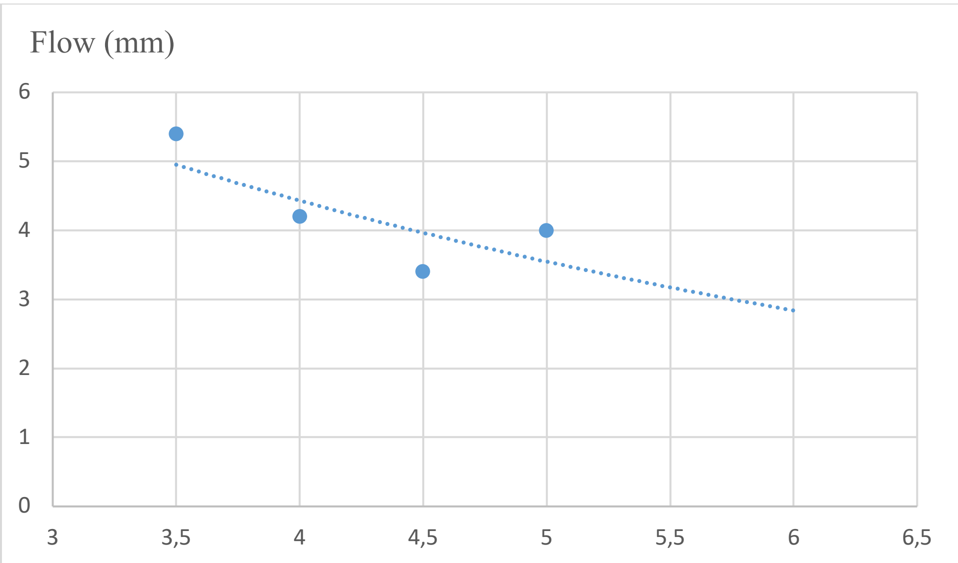

Fig. 7. Flow values

Fig. 7. indicates that the HMA mixture with a 3.5% bitumen content provides the highest flow value, while the HMA mixture with a 4.5% bitumen content provides the lowest flow value. It was observed that the addition of 4% bitumen results in a higher flow value compared to the addition of 5% bitumen. HMA mixtures with 4.5% and 5% bitumen content remained within the specified limits according to the KGM specification. The flow values of HMA mixtures with 3.5% and 4% bitumen content exceed the specified limit values in the specification.

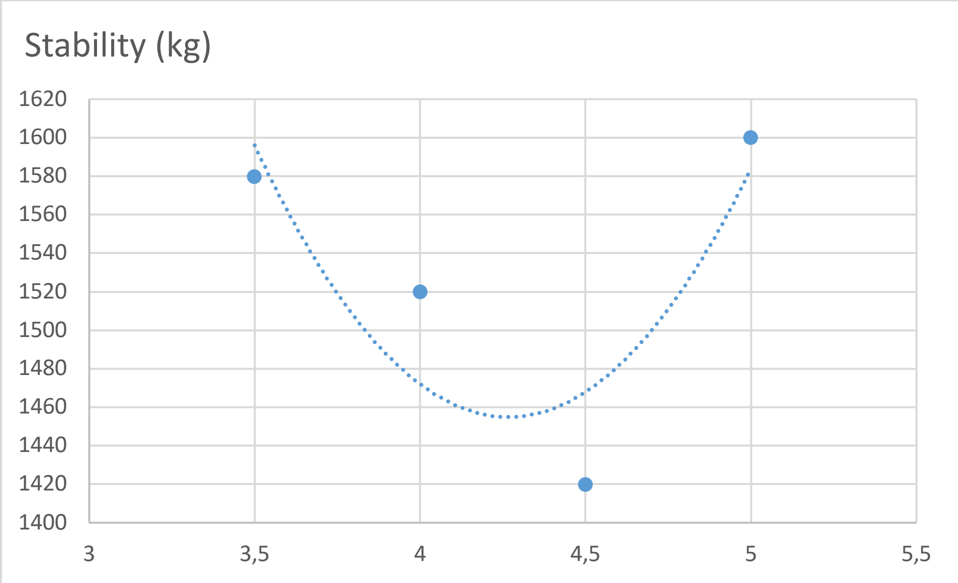

Fig. 8. Stability values

In Fig. 8., it is observed that the HMA mixture with a 4.5% bitumen content provides the lowest stability value, while the HMA mixture with a 5% bitumen content provides the highest stability value. The HMA mixture with a 4% bitumen content is lower compared to the HMA mixture with a 3.5% bitumen addition. Each HMA mixture prepared according to the KGM specification has exceeded the specified lower limit value.

The volumetric specific gravity (Dp) of the test specimens was determined by measuring the weight in air, weight in water, and saturated surface-dry weight for each HMA specimen removed at room temperature. After calculating the maximum theoretical specific gravity (Dt), the air void content (Vh), voids in mineral aggregates (VMA), and voids filled with bitumen (VFA) were determined, and the optimum bitumen content of the HMA mixtures was obtained from the graphs. Flow and stability results were obtained by conducting Marshall stability tests. The results obtained from the graphs are summarized in Table 4.

Table 4. Summarized Marshall test results

					Specification
Animal bone ash%	3	3	3	3	…...
Bitumen %	3.5	4	4.5	5	4--7
Dp (g/cm³)	2.419	2.352	2.361	2.395	…...
Dt (g/cm³)	2.53	2.46	2.47	2.5	…...
Vh %	4.377	4.387	4.43	4.192	3--5
V.M.A. %	14.664	14.994	16.734	15.513	min. 14
VFA %	70.153	70.708	73.528	72.978	65--75
Flow (mm)	5.4	4.2	3.4	4	2--4
Stability (kg)	1580	1520	1420	1600	min. 900

As seen in Table 4, the air void content (Vh) of each HMA mixture specimen remains within the specified range of 3-5% according to the KGM specification. The voids in mineral aggregates (VMA) are associated with the deformation resistance and durability of the asphalt mixture. According to the KGM specification, the VMA value should be a minimum of 14%. Each HMA specimen meets the minimum specification criterion.

According to the KGM specification, the voids filled with bitumen (VFA) in the asphalt should be between 65-75%. Each of the prepared HMA specimens falls within these limit values.

Marshall stability and flow tests were conducted according to TS EN 12697-34 standard. In the standard, stability is defined as the maximum resistance to deformation, and flow is defined as the deformation that occurs in the specimen when it reaches maximum load. According to the KGM specification, the minimum stability value is 900 kg, while the flow limit values range between 2-4 mm.

According to the test results, all specimens prepared with the addition of 5% animal bone meet the minimum stability value, using different bitumen percentages. When evaluating the flow values of specimens prepared with different bitumen percentages with the addition of animal bone together, it is determined that specimens containing 4.5% and 5% bitumen meet the specification limits.

3.2.2 Modified Lottman test results (AASHTO T-283)

For the experiment, an optimum bitumen-animal bone ash ratio of 5% was selected, and 3 unconditioned (dry) and 3 conditioned (wet) specimens were prepared in compliance with the specifications. As a result of the experiments, indirect tensile strength (ITS) values were determined.

ITSR: Indirect tensile strength ratio (%), ITS_wet: Average indirect tensile strength of the conditioned (wet) group (kPa), ITS_dry: Ratio of average indirect tensile strength of the unconditioned (dry) group (kPa) were calculated. The results of the experiments are shown in Table 5., Table 6. and Table 7.

Table 5. Unconditioned sample Modified Lottman test (AASHTO T-283) results

SAMPLE TYPE	No	Unconditioned Samples		
		Height (mm)	P max (kN)	ITS dry (kPa)
B+%5 BA	5	62.8	23.53	2329
	6	62.4	29.75	2967
	7	62	26.01	2631
			ITS_{dry} average=	2642.33

As seen in Table 5., the specimen prepared with a 5% bitumen content, specifically the B6 specimen with a height of 62.4 mm, exhibits the maximum load-carrying and tensile strength. The B5 specimen has the lowest tensile and load-carrying capacity, whereas the B7 specimen demonstrates greater tensile and load-carrying capacity compared to the B5 specimen.

Table 6. Conditioned sample Modified Lottman test (AASHTO T-283) results

SAMPLE TYPE	No	Conditioned Samples		
		Height (mm)	P max (kN)	ITS wet (kPa)
B+%5 BA	1	63.9	19.15	1868
	2	62.5	21.94	2191
	3	63.2	18.68	1843
			ITS_{wet} average=	1967.33

As observed in Table 6., the specimen prepared with a 5% bitumen content, specifically the B2 specimen with a height of 62.5 mm, exhibits the maximum load-carrying and tensile strength. The B3 specimen has the lowest tensile and load-carrying capacity, while the B1 specimen demonstrates greater tensile and load-carrying capacity compared to the B3 specimen.

Table 7. ITSR value

ITSR (%)
ITS_{wet}/ITS_{dry}=0.74

The modified Lottman test was utilized to determine the resistance of the asphalt concrete mixture to water damage using the optimum bitumen content. Indirect tensile strength tests were conducted on conditioned and unconditioned identical specimens of the HMA mixture. Three samples were used for each option, and the average of the values obtained from the three samples was considered. The ITSR value was determined by comparing the ITS values of conditioned and unconditioned specimens. The calculations are summarized in Table 5. According to the KGM specification, the minimum ITSR value should be 0.80, but the conducted experiment did not meet this requirement. The ITSR value obtained from the experiment was 0.74, indicating that the sample has low tensile strength and is prone to cracking and deformation.

5. Conclusion and Recommendations

This study aims to explore a more economical and beneficial way to recycle animal bones, a type of environmental waste, for use in asphalt pavement. Previous research suggests that animal bone ash can increase the tensile strength and improve the flexibility of asphalt mixtures. Furthermore, the use of recycled materials can reduce costs, contribute to the reduction of environmental waste, and help us use resources more efficiently.

From the findings of this study, it can be concluded that the stability value of each HMA mixture remains above the minimum specified limit in the relevant specifications, which could be attributed to the finer particles of animal bone ash having a larger surface area, thus enhancing the asphalt and improving deformation resistance. Building upon previous studies, the higher percentage of calcium in bone ash promotes better bonding, contributing to the improvement of mechanical properties of asphalt.

HMA mixtures prepared with 4.5% and 5% bitumen content did not meet the flow limit values and were not compliant with the specifications. This may be due to the proportion of animal bone ash, as the decrease in bitumen percentage also reduces the proportion of animal bone ash in the mixture. The decrease in the percentage of animal bone ash leads to increased air voids between aggregates, resulting in decreased stability and increased flow, as well as a decrease in the voids filled with asphalt.

Experimental findings confirm this situation. It is known that the highest animal bone content is in the 5% bitumen sample, and the lowest animal bone ash content is in the 3.5% bitumen sample. According to the test results, the highest stability value is observed with 5% bitumen addition, while the highest flow value is observed with 3.5% bitumen addition.

The sample with 5% bitumen addition was selected as the optimum bitumen, and the modified Lottman test was performed based on these sample ratios.

According to the experimental findings, the indirect tensile strength ratio (ITSR) being 0.74 indicates that the asphalt mixture does not meet the standard requirements for tensile strength and elastic properties. The fact that it does not meet the minimum requirement of 0.80 specified by the relevant authority suggests that the mixture may be more susceptible to cracking and deformation. Therefore, the use of bone ash may have adverse effects on tensile strength (ITS) and maximum load capacity (Pmax). However, in the original Lottman test, an ITSR value of at least 0.70 is considered sufficient.

Using HMA mixtures in asphalt reduces the use of traditional highway materials, thus reducing costs and helping to reduce the environmental damage caused by waste materials.

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Author Contributions

Burak Ontas: Conceived and designed the analysis, Performed the analysis, Wrote the paper, Modified the paper.

Julide Oner: Conceived and designed the analysis, Contributed data and analysis tools, Performed the analysis, Wrote the paper.

References

[1] Dağdelen, E., *Investigation of the Effect of Heat on the Physical Properties of Asphalt Concrete,* Firat University Institute of Science; Master's Thesis, 1995.

[2] Al-Hadidy, A.I., Tan, Y.Q., Mechanistic analysis of ST and SBS-modified flexible pavements. *Construction and Building Materials,* 23(8), 2941-2950, 2009.

[3] Şengöz, B., Topal, A., Use of asphalt roofing shingle waste in HMA. *Construction and Building Materials,* 19(5), 337-346, 2005.

[4] Polat, H., *Analysis of the Physical Properties and Compaction of Bituminous Mixture Surface Layers of Ankara Gerede, Ankara Ring Road,* Gazi University Institute of Science,1994.

[5] TS 118: Petroleum products, determination of needle penetration of bitumens and bituminous binders, *Turkish Standards Institution,* 1998.

[6] Thom, N., Elliott, R., *Asphalt properties and test methods: In ICE Manual of Construction Materials*, Fundamentals and Theory; 1nd edition, 2009.

[7] Zaumanis, M., Mallick, R. B., Examining the use of very high content reclaimed asphalt in plant-produced asphalt mixtures. *International Journal of Pavement Engineering,* 15(1), 39–55, 2014.

[8] Yan, K. Z., Xu, H. B., Zhang, H. L., Effect of mineral filler on properties of warm asphalt mastics containing Sasobit. *Construction and Building Materials*, 48, 622–627, 2013.

[9] Huang, Y., Bird, R. N., Heidrich, O., A review of the use of recycled solid waste materials in asphalt pavements. *Resources, Conservation and Recycling*, 52(1), 58–73, 2007

[10] Bindu, C. S., Joseph, M. S., Sibinesh, P. S., George, S., Sivan, S., Evaluation of warm mix asphalt performance using natural rubber modified bitumen and cashew nut shell liquid. *International Journal of Pavement Research and Technology*, 13(4), 442–453, 2020.

[11] Sung D., Hwang., Park H.M., & Rhee S.K., An Investigation on the Engineering Properties of Asphalt Concretes with Recycled Lime Filler. *Waste Management,* 28(1), 191–199, 2008.

[12] Modarres, A., Rahmanzadeh, M., Application of waste coal ash in hot mix asphalt as filler. *Construction and Building Materials,* 66, 476–483, 2014.

[13] El-Busaltan, Ş., Evaluation of Asphalt Mixtures Containing Waste and By-Product Material Fillers. Kerbela University Journal, (2), 130-141, 2016.

[14] Tahami, S. A., Arabani, M., & Mirhosseini, A. F., Use of two biomass ashes as filler in hot mix asphalt. *Construction and Building Materials*,170, 547–556, 2018.

[15] Sharma, V., Chandra, S., Choudhary, R., Characterization of fly ash-bitumen modified mixes. *Construction and Building Materials*, 24(12), 2354–2360, 2010.

[16] Choi, M. J., Kim, Y. J., Kim, H. J., Lee, J. J., Performance evaluation of rubber-derived fuel fly ash as mineral filler in hot mix asphalt. *Journal of Traffic and Transportation Engineering*, 7(2), 249–258, 2020.

[17] Choudhary, J., Kumar, B., Gupta, A., Application of waste materials as filler in bituminous mixes. *Waste Management*, 78, 417–425, 2018.

[18] Tarbay, E. W., Azam, A. M., El-Badawy, S. M., Asphalt mixtures with waste materials and by-products as mineral fillers. *Innovative Infrastructure Solutions*, 4(1), 1–13, 2018.

[19] Sargın, Ş., Saltan, M., Morova, N., Serin, S., Terzi, S., Evaluation of rice husk ash as filler in hot mix asphalt concrete. *Construction and Building Materials,* 48, 390–397, 2013.

[20] Yüceer, A., Çelik, O. N., The use of polymers in asphalt concrete and evaluation of waste plastics. *Chamber of Civil Engineers Journal,* 227-234, 1991.

[21] Yıldırım, Y., Polymer modified asphalt binders. *Construction and Building Materials*, 21, 66-72, 2005.

[22] Navarro, F. J., Partal, P., Martinez-Boza, F., Gallegos, C., Valencia, C., Thermo-rheological behaviour and storage stability of ground tire rubber-modified bitumens. *Fuel,* 83(14), 2041–2049, 2004.

[23] Ruan, Y., Davison, R. R., Glover, C. J., The effect of long-term oxidation on the rheological properties of polymer modified asphalts. *Fuel,* 82(15–17), 1763–1773, 2003.

[24] Navarro, F. J., Partal, P., Martinez-Boza, F., Valencia, C., Gallegos, C., Rheological characteristics of ground tire rubber-modified bitumens. *Chemical Engineering Journal*, 89(1–3), 53–61, 2002.

[25] Lu, X., & Isacsson, U., Modification of road bitumens with thermoplastic polymers. *Polymer Testing*, 20(1), 77–86, 2001.

[26] Isacsson, U., Lu, X., Characterization of bitumens modified with SEBS, EVA and EBA polymers. *Journal of Materials Science*, 34(16), 3737–3745, 1999.

[27] Raza, H., Rizvi, Khattak, M. J., Gallo, A. A., Rheological and mechanistic properties of bone adhesive-modified asphalt binders. *Construction and Building Materials*, 88, 64–73, 2015.

[28] Muhammed, A., Aboje, A. A., Auta, M., Cibril, M., Comparative analysis and characterization of bone adhesive as adsorbent. *Pelagia Research Library Advances in Applied Science Research,* 3(5), 3089–3096, 2012.

[29] Asif, A., Ahmed, N., Adeel, M., Zaidi, S. B. A., Jameel, M. S., Qureshi, F. A., Asif, S. A., Performance evaluation of bone glue modified asphalt. *Advances in Materials Science and Engineering*, 3157152, 2019.

[30] Ahmedzade, P., The investigation and comparison effects of SBS and SBS with new reactive terpolymer on the rheological properties of bitumen. *Construction and Building Materials,* 38, 285–291, 2013.

[31] Gökalp, İ., Uz, V. E., Investigation of the Effect of Waste Vegetable Cooking Oils on the Properties of Pure Bitumen. *Journal of Engineering Sciences and Design*, 6(4), 570–578, 2018.

[32] Gökalp, İ., Uz, V. E., Utilizing of Waste Vegetable Cooking Oil in Bitumen: Zero Tolerance Aging Approach. *Construction and Building Materials,* 227, 116695, 2019.

[33] Bagampadde, U., *Investigations on Moisture Damage-related Behaviour of Bituminous Materials*. Civil and Architectural Engineering; Doctoral Thesis, 2005.

[34] Hunter, E. R., *Evaluating Moisture Susceptibility of Asphalt Mixes*. University of Wyoming; Laramie, 2001.

[35] Zaniewski, J., Viswanathan, A. G., *Investigation of Moisture Sensitivity of Hot Mix Asphalt Concrete,* West Virginia University, 2006.

[36] Balta, İ., *Sensitivity of Bituminous Hot Mixtures to Moisture-Induced Deterioration.* Dokuz Eylül University Institute of Science, Izmir; Master's Thesis, 2004.

[37] Lavin, P.G., *Asphalt Pavements*, Spon Press, London and New York, 444p, 2003.

[38] The Asphalt Institute: *Superpave Mix Design*, Superpave Series No. 2 (SP-2), U.S.A, 1996.