International Journal of Computational and Experimental Science and ENgineering
(IJCESEN)

Vol. 10-No.4 (2024) pp. 1644-1650
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Bitumen quantity reduction for stone mastic asphalt (SMA) – suitable material for the environment

Mazllum KAMBERI[1], Hajdar SADIKU[2]*

[1]University of Prishtina "Hasan Prishtina", Faculty of Civil Engineering, 10000, Prishtina-Kosovo
Email: mazllum.ing@gmail.com - **ORCID:** 0009-0002-2043-5995

[2]University of Prishtina "Hasan Prishtina", Faculty of Civil Engineering, 10000, Prishtina-Kosovo
* **Corresponding Author Email:** hajdar.sadiku@uni-pr.edu - **ORCID:** 0000-0001-5127-9943

Article Info:

DOI: 10.22399/ijcesen.689
Received : 26 November 2024
Accepted : 12 December 2024

Keywords :

bulk density,
marshal test,
modify bitumen,
quality assurance,
mix design.

Abstract:

This paper describes the mix design (recipe) for SMA that consists of aggregate obtained from stone with relatively high specific gravity and relatively high refractive index (LA>16) but which significantly reduces the amount of Bitumen. and in this case, it also reduces the amount of carbon emissions in the environment.
For the production of stone mastic asphalt is used aggregate produced from stone with special mineralogical and petrographic characteristics. The aggregate used for the wearing course of the highway has a coefficient of resistance to crushing Los Angeles LA = 18 and a specific mass greater than 3000kg / m3. Los Angeles coefficient does not meet the standard requirements for the road layer with heavy traffic and the maximum bulk density is greater than the bulk density of ordinary aggregates used for this type of asphalt. Also, for the production of stone mastic asphalt SMA for the highway is used bitumen with additives in the amount of 4.6%, a quantity that is smaller than the amount of bitumen provided by the standard for stone mastic asphalt which is 6-7%. However, the designed mix with the aggregate produced from M.G quarry stone and with the amount of polymerized bitumen (with polymer additives) (4.6%) has met the requirements for SMA stone mastic asphalt it also increases its performance in protecting the environment.

1. Introduction

For asphalt mix design current practices rely on the specific weights of the mixing constituent materials. First mix of SMA invented in 1960 in Germany. Today, the use of SMA mix has become popular in the United States and developed [1, 2]. In Kosovo for the construction of two highways, therefore it was necessary that the aggregate be provided locally and not exported because there would be damage to the roads as well as direct pollution of the environment in road segments over 100km. Results showed that the use of asphalt mixtures formulated with bitumen modified with had the lowest environmental impact, with a decrease compared to traditional pavement [3, 4]. Essentially, specific weight measurements are important factors in determining the amount of material participating in asphalt mix design (HMA) as the total mass of materials in the mix must not exceed 1m3 by volume. The benefits of SMA over HMA mixes are the improvement of skidding resistance, the increment of endurance of reflective cracks, and the lessening of noise pollution [1, 2, 5] This mixture has a surface appearance similar to that of an open graded friction course; however it has low in-place air voids similar to that of a dense graded hot mix asphalt HMA [6]. The road structure includes a large volume which is filled with different materials in certain layers. The homogeneity of the material in the whole surface of the layers as well as their control is much more difficult than what the engineer who designs the road wants, therefore he must take it into account during the design. Waste materials used in asphalt mixture to replace the original aggregate may derive from various sources, such as waste glasses waste plastics. Concrete construction demolition, recycled asphalt pavement and shingle, waste tire rubber, coal bottom ash, marble waste, basalt waste, mining waste, and redbrick. Use of waste materials in asphalt pavement minimizes construction cost and preserves the nature by reducing the need to harvest natural aggregates from sources, where the natural production of aggregate consumes more time [7].

The purpose of the design of the road structure by the engineers is to limit the deformations, the limitations of the cracks as well as the limitation of the serious damage of the road layers in the whole for a time as optimal as possible from the impact of the traffic loads. There are four key considerations which influence the accuracy of traffic estimates, and which can significantly influence the life cycle of a pavement:

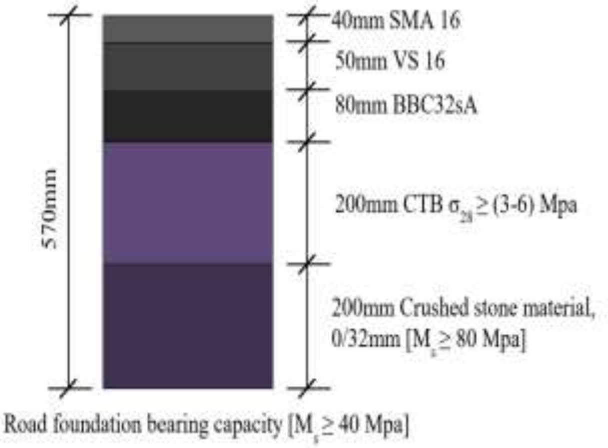

Figure 1. *Pavement structure layers.*

The correctness of the load equivalency values used to estimate the relative damage inducted by axle loads of different mass and configurations, The accuracy of traffic volume and weight information used to represent the actual loading projections. The prediction of ESAL's over the design period, and the interaction of age and traffic as it affects changes in PSI. For the Kosovo highway, the method of mechanical-empirical design was used to determine the thickness of the layers and the structure of the highway. To use this method, the climatic conditions, and the traffic load for the period of 20 years must be considered. Stone mastic asphalt was first used in the United States in 1988 but for the first time it was produced in Europe. Contains a higher percentage of cement as well as binders with additives and specifically designed to enable proper friction with the asphalt layer. The physical properties and chemical attributes of filler, along with its quantity in the mastic, modify mastic's viscosity and consistency, thereby influencing the overall performance of bituminous mixes [8, 9]. This type of asphalt is relatively expensive when compared to other asphalt pavements and is generally only used on very large projects [10]. Life cycle assessment (LCA) is a method for assessing the environmental impact of a product throughout its life cycle. This is important as it encourages road designers to use stone mastic asphalt with more suitable preferences for the protection of the environment. A wearing course made from stone mastic asphalt with the correct design and mix production as well as proper paving shows the following characteristics due to the high chippings content together with the mastic-like mortar:

- better resistance to permanent deformation
- high wearing resistance
- less cracking due to cold or mechanical stress
- coarse surface texture
- good macro roughness
- good long-term behaviour

The higher percentage of coarse aggregate skeleton provides stone-on-stone interlock to induce a resistance against permanent deformation and vehicular skidding [11], while the superior binder mastic adds to the durability and stability of SMA against pavement distresses by adhering along the coarse aggregate [1]. During the construction process of the Ibrahim Rugova highway in Kosovo, the problem of aggregate export to produce stone mastic asphalt for the upper layer of the road construction is presented. In Kosovo, aggregate was produced for the upper layers, but there were some problems related to the criteria required by the standard, such as the Los Angeles coefficient greater than LA>16 and the high specific weight, therefore there was a need to verify the quality of the asphalt produced by this type of aggregate.The main purpose of this work is to research the quality of aggregate and asphalt produced with this aggregate was researched in three different institutes in Slovenia, Croatia, and Kosovo. Pavement structure consists of wearing course from Stone Mastic Asphalt (SMA 16) – thickness 40mm, binder layer from VS 16 - thickness 50 mm, bituminous bearing layer (BBC 32s A) – thickness 80mm, base course cement stabilized (CTB) thickness 200mm and granular stone material 0/32mm-thickness 200mm. Cross-section of the structure of the Highway is presented in figure 1.

2. Materials and methods

2.1 Study area

The mineralogical and petrographic composition as well as the physical and mechanical characteristics of the stone directly affect the production of the aggregate, which can be used in the wearing course layer of the road.

2.2 Materials

The quality of the stone as a raw material to produce aggregate for asphalt for wearing course layer, must meet some of the criteria that are presented below:

- Compressive strength in dry state, minimum 160Mpa high wearing resistance
- Resistance to wear by sanding, maximum 12cm3/50cm2 coarse surface texture
- Water absorption, maximum, 0.75% (m/m)
- Los Angeles (Resistance to crushing) maximum 16%

Because in Kosovo there was no aggregate in production with a coefficient of resistance to crushing (Los Angeles) LA <16 as required by the EN standard for the stones used to produce asphalt for the layer of the erosion layer on the Highway. The aggregate to produce Stone Mastic Asphalt (SMA) is produced from the stone, which is found in Golesh, a mountain near municipality of Lipjan, the location and a photo of which are presented in figure 2. The new mix design for stone mastic asphalt using Granular stone from the quarry near the Highway (M.G quarry) with the following main characteristics has been considered:The coefficient of resistance to crushing (Los Angeles) LA = 18, Maximum bulk density of aggregate sum=3100kg/m3. For the realization of the mix design for stone mastic asphalt SMA with the grains size of aggregate 16mm, which is used for the wearing course layer of the Highway, 6 samples (mixture) have been prepared based on standard procedures. Table 1 shows the granulometric composition of the designed asphalt mixtures, while table 2 presents their composition and properties. deformation and cracking can lead to a reduction in the amount of pollutants released into the environment. The final mix designed for stone mastic asphalt SMA 16 for the wearing course layer The density of bitumen used for the preparation of asphalt mix design determined according to the Marshall method (EN 15326), the method with Picknometer is ρB = 1011 kg / m3. The type of bitumen is polymer modified bitumen PmB45 / 80 65 and the bitumen content in the mix design for stone mastic asphalt SMA 16 is 4.6%. The modification of bitumen with polymers is carried out in the construction site where fibres are used for modification, commonly used additives are fibres, such as cellulose fibres. Two types of admixtures with a total amount of 1% by mass of bitumen prefer used in the mix design [8, 9]. Environmental Impact of PMB- While still derived from petroleum, the enhanced durability and lifespan can lead to reduced environmental impact over time. Consider the environmental impact of the materials. PMB may offer a longer. service life, potentially reducing the need for frequent repairs and replacements. PMB's enhanced resistance to of the Highway in Kosovo is presented in the table 3. The granulomere curve of the aggregate used for stone mastic asphalt SMA 16 specified in the IGH, RAMTECH and PROING laboratories is shown in figure 3.

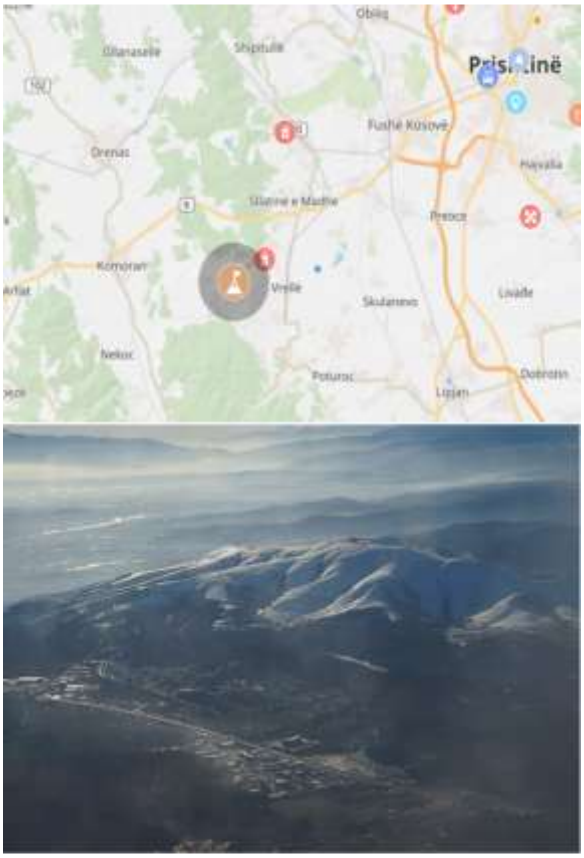

Figure 2. *Location of mountain Golesh*

2.2 Methods

The research methodology is based on experimental research in the field and in laboratories in accordance with the European testing standards for both the components of the asphalt and especially the aggregate by the M.G quarry, as well as the preparation and testing of the asphalt samples. The sieving method for determining the granulometry of aggregate, determining the specific weight with a pycnometer, the los angeles method for determining the fraction of the aggregate, Cone and plate method, determination of needle penetration, ring and ball method of bitumen, Extraction of asphalt for determining the amount of bitumen, granulometry as well as determining the voids content, VFB in the asphalt mixture, Marshall methods for Compaction, stability, deformation, determination of compactness by non destructive methods using the PQI device, water method for adjusting the asphalt density of the samples taken from the ground and the samples prepared with a compactor for determining the compactness of the asphalt layer on site. To test the new stone mastik asphalt (SMA) mix design, a 350m section of road was paved. The following tests were performed on this part of the road.

Table 1. *Granulometric composition of the designed asphalt mixtures*

	Relation P(KB)/P(FKM)	Filler in KM[%m/m)]	Coefficient for RF	0/4	4/8	8/11	11/16
M1	2.4	6.5	5.05	21.80	16.12	15.60	41.43
M2	2.4	6.5	5.05	21.80	16.12	15.60	41.43
M3	2.4	6.5	5.05	21.80	16.12	15.60	41.43
M4	2.9	7.0	5.73	21.65	16.12	15.40	41.43
M5	3.7	8.3	7.27	21.32	15.74	15.15	40.38
M6	5.0	10.0	9.17	20.80	15.43	14.82	30.08

Table 2. *Composition and properties of designed asphalt mixtures*

	Density of mixture FKM [t/m^3]	Density AM [t/m^3]	Percentage of bitumen content in AM [%(m/m)]
M1	3.071	2.819	4.21
M2	3.071	2.888	3.94
M3	3.071	2.818	3.81
M4	3.068	2.861	4.00
M5	3.062	2.811	4.02
M6	3.055	2.802	4.14

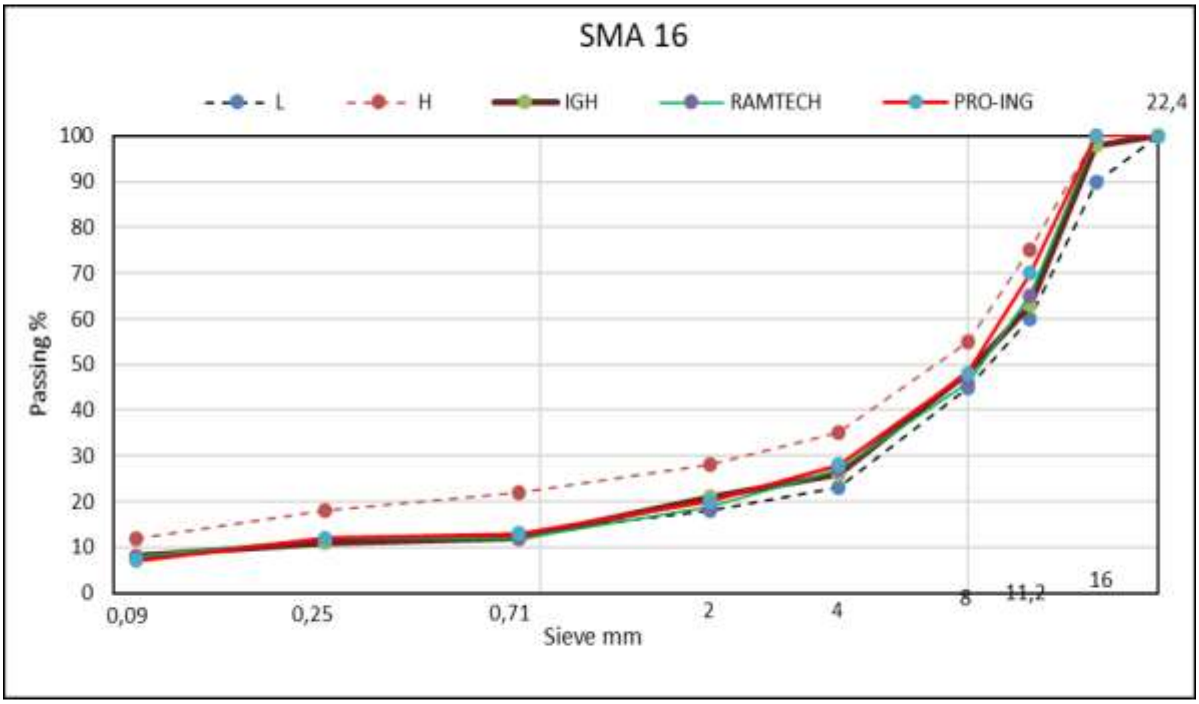

Figure 3. *Grain size distribution curve of the aggregate used for stone mastic ashpalt (SMA)*

Table 3. *Mix design for stone mastic asphalt SMA 16*

Aggregate, bitumen and admixture	[%]
Filler (Cement)	7.1
0-4 (M. G)	20.5
4-8 (M. G)	15.9
8-11 (M. G)	19.2
11-16 (M. G)	37.3
Content of bitumen	4.6
Admixture I	0.5
Admixture II	0.5

3. Results und Discussion

At the time of asphalting, the asphalt temperature was measured in each truck. The general trend here is that the compaction window is getting wider as the temperature decreases [12]. Determination of physical characteristics: Bulk Density and Maximum Bulk Density. Bulk density of an intact compacted bituminous specimen is determined from the mass of the specimen and its volume. The mass of the specimen is obtained by weighing the dry specimen in the air. The test methods given in BS EN-12697-6 are designed for use with laboratory compacted materials or specimens taken from the pavement following coring or sawing. It can assist in preventing specimen damage throughout the separation procedure [13-15]. Test methods described are intended for use with loose bituminous materials containing paving grade bitumen, modified binders or other bituminous binders used for bituminous mixes. The tests are suitable for both fresh or aged bituminous materials. Determination of Mechanical characteristics stability according to marshal is determined with standard EN-12697-34, and in this investigation its determined and indirect ratio of tensile strength [16-19]. Determination of asphalt compaction by non-destructive field methods in at least sixpoints. For an asphalt mixture are important attributes good compatibility and workability for the construction of durable asphalt pavements [12]. Has been done research about correlation between laboratory compaction and on-site compaction, and investigated the parameters that affected the compaction characteristics of the mixture, including: CEI, Bailey method ratio parameters, slopen of the compaction curve, locking point and number of rotation compactions required to reach 92% Gmm (N at 92% Gmm) [15]. Compaction rate, percentage of voids EN-12697-8, thickness of the executed layer, in at least three original samples. The asphalt mastic fills the gaps within the stone skeleton and binds loose stones together, thus creating the desired air voids. Additionally, considering the importance of void characteristics as volumetric parameters of asphalt mixtures and their pivotal role in analysing pavement water seepage, it is crucial to conduct comprehensive research on water seepage by investigating the morphological distribution characteristics of internal voids [4]. Some studies have shown that the degradation of macro-texture and micro-texture is the main reason that the skid resistance does not meet the requirements under the repeated action of heavy traffic loads. In pavement engineering, there are two groups of engineering parameters influencing the skid resistance evolution. The first are pavement inherent properties, such as aggregates and asphalt mix properties. In more detail, the lithological nature of aggregates affects the pavement-surface texture deterioration behaviour under traffic actions, resulting in the skid-resistance changes. Figure 4 shows: measurement of asphalt temperature before asphalting, measurement of compaction rate by non-destructive method, compaction phases, determination of skid resistance. Test results performed in the field and laboratory are presented in table 4. From the research of the literature for the final layers of the road, we have not come across cases of using aggregate with coefficient La>16 and specific weight >3000kg/m3. Based on laboratory and field test results Stone mastic asphalt (SMA 16) produced with aggregate from the M.G quarry fully meets the criteria according to European standards. Therefore, the mixture designed for stone mastic asphalt which contains the aggregate of the M.G quarry can be used for the wearing course of the highway in Kosovo. After determining of the mix design for SMA, the quality of the produced asphalt was maintained throughout the asphalting of the wearing course layer of the highway with a length of about 60 km. The testing of the samples was carried out in the field laboratory of the Bechtel Enka company and in the IPE Proing Institute. All test results have met the criteria required by the standard (SISTEN-12697-8-2019). Based on the research results we can conclude that the aggregate which is used. To produce the wearing course layer asphalt is not necessary to meet the criteria of the standards for the coefficient of resistance to crushing (Los Angeles) La = max 16%, and maximum bulk density as specify standards standards or general technical requirements - to be used to produce stone mastic asphalt (SMA). The quality of the stone as a raw material to produce the aggregate must meet the This type of stone which is used to produce aggregate for stone mastic asphalt (SMA), has reduced the minimum required amount of bitumen by more than 20% (from 6% to 4.6%). in this case, the impact on environmental protection will be greater.

3. Conclusions

The mix design of stone mastic asphalt (SMA) used on the Kosovo Motorway requires less compaction energy than previously produced reference mixes.

Figure 4. *Measurement of asphalt temperature before asphalting, measurement of compaction rate by non-destructive method, compaction phases, determination of skid resitance*

Table 4. *Laboratory testing results and mechanical-physical properties for stone mastic asphalt*

No.	Technical characteristics	Laboratory Results	Quality conditions	Standard
1	Voids content, [%]	4.8	3 - 6	(*SIST-EN-12697-8-2019*)
2	VFB, [%]	75.8	71 - 83	
3	ITSR [%]	87.93	≥ 80	EN-12697-12 (*SIST-EN-12697-23-2018*)
4	WTSAIR [%]	0.0342	≤ 0.07	(*SIST-EN-12697-22-2020*)
5	PRDAIR [%]	4.36	≤ 5.0 [%]	
6	Stiffness [MPa]	4022	3600 - 7000	EN-12697-26
7	Density [kg/m3]	2702	-	(*SIST-EN-12697-6-2012*)
8	Specific Density [kg/m3]	2828	-	(*SIST-EN-12697-5-2010*)
9	Compaction, [%]	99	98	
10	Marshal Stability [kN]	8.6	-	(*SIST-EN-12697-34-2012*)
11	Strains [mm]	3.6	-	
12	S/D [kN/mm]	2.30	-	
13	Bitumen cont. [%]	4.6		EN 15326

With the increase of the Maximum Bulk Density of the aggregate, the Bulk Density of the asphalt also increases, therefore it should be considered that the price is tuned to the mass of the asphalt, because the cost can be increased by ~ 10%.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1]P.K. Akarsh, G.O. Ganesh, SH. Marathe and R. Rai.(2022). Incorporation of Sugarcane Bagasse Ash to investigate the mechanical behavior of Stone Mastic Asphalt. *Construction and Building Materials* 353;129089 https://doi.org/10.1016/j.conbuildmat.2022.129089

[2] M. Fakhri, T. Ahmadi, E. Shahryari and M. Jafari. (2022). Evaluation of fracture behavior of stone mastic asphalt (SMA) containing recycled materials under different loading modes at low temperature. *Construction and Building Materials* 386;131566 https://doi.org/10.1016/j.conbuildmat.2023.131566

[3] C. A. Vargas, G. R. Lu and A. E. Hanandeh. (2023). Environmental impact of pavements formulated with bitumen modified with PE pyrolytic wax: A comparative life cycle assessment study. *Journal of Cleaner Production* 419;138070 https://doi.org/10.1016/j.jclepro.2023.138070

[4]ZH. Cheng, F. Kong, CH. Duan, T. Wang and X. Zou. (2023). Temperature-dependent voids and their impact on SMA surface course permeabilit. *Construction and Building Materials* 406;133463 https://doi.org/10.1016/j.conbuildmat.2023.133463

[5] S. Zhu, X. Ji, H. Yuan, H. Li und X. Xu. (2023). Long-term skid resistance and prediction model of asphalt pavement by accelerated pavement testing. *Construction and Building Materials* 375; https://doi.org/10.1016/j.conbuildmat.2023.131004s

[6]A. Khodaii, H. F. Haghshenas und H. K. Tehrani (2012). Effect of grading and lime content on HMA stripping using statistical methodology. *Construction and Building Materials* 34;131-135 https://doi.org/10.1016/j.conbuildmat.2012.02.025

[7] Y. Meng, J. Lai, L. Ling, CH. Zhang, J. Chen und J. Zhu. (2023). Preparation of an eco-friendly de-icing filler and its effects on the performance of different asphalt mastic. *Construction and Building Materials* 364; 129967 https://doi.org/10.1016/j.conbuildmat.2022.129967

[8] R. Guo, F. Zhou, und T. Nian. (2022). Indices relation and statistical probability analysis of physical and mechanical performance of asphalt mixtures. *Case Studies in Construction Materials* 16; e01091 https://doi.org/10.1016/j.cscm.2022.e01091

[9] R. Guo, T. Nian, und F. Zhou. (2020) Analysis of factors that influence anti-rutting performance of asphalt pavement. *Construction and Building Materials* 254;119237 https://doi.org/10.1016/j.conbuildmat.2020.119237

[10] J.Mrugacz. (2014). Understanding the differences between hot mix asphalt and warm mix asphalt. *Wolf paving* https://www.wolfpaving.com/blog/understanding-the-differences-between-hot-mix-asphalt-and-warm-mix-asphalt#:~:text=Warm%20Mix%20Asphalt,-Warm%20mix%20asphalt&text=WMA%20is%20less%20costly%20to,paving%20and%20road%20construction%20months.

[11] D. Zheng, ZH. Qian, Y. Liu und CH. Liu. (2018). Prediction and sensitivity analysis of long-term skid resistance of epoxy asphalt mixture based on GA-BP neural network. *Construction and Building Materials* 158; 614-623 https://doi.org/10.1016/j.conbuildmat.2017.10.056

[12]A. Margaritis, T. Tanghe, S. Vansteenkiste, J. Visscher und A. Vanelstraete (2023). Impact of the mastic phase and compaction temperature on the sigmoidal gyratory compaction curve of asphalt mixtures. *Construction and Building Materials* 391; 131283 https://doi.org/10.1016/j.conbuildmat.2023.131283

[13]A. Singla und N. Dhingra (2024). Investigation of impact of soil texture, depth and gamma ray energy on the mass attenuation coefficient and determination of soil bulk density using Gamma-Ray Spectrometry. *Radiation Physics and Chemistry* 216;111400 https://doi.org/10.1016/j.radphyschem.2023.111400

[14]R. B. Malidarre, H. O. Tekin, K. Gunoglu, H. Akyildirim (2023). Assessment of Gamma Ray Shielding Properties for Skin. *International Journal of Computatuonal and Experimental Science and Engineering* 9(1);6-10 https://doi.org/10.22399/ijcesen.1247867

[15]Y. Bi, J. Huang, J. Pei, J. Zhang, F. Guo und R. Li (2021). Compaction characteristics assessment of HotMix asphalt mixture using Superpave gyratory compaction and Stribeck curve method. *Construction and Building Materials* 285;122874 https://doi.org/10.1016/j.conbuildmat.2021.122874

[16]H. Sadiku, M. Kamberi, G. Nafezi (2024). Creep Coefficient for Self-Compacting Concrete (SCC). *International Journal of Computatuonal and Experimental Science and Engineering* 10(3);292-298 https://doi.org/10.22399/ijcesen.1247867

[17]Cena, B. (2024). Determination of the type of radioactive nuclei and gamma spectrometry analysis for radioactive sources. *International Journal of Computational and Experimental Science and Engineering,* 10(2);241-246. https://doi.org/10.22399/ijcesen.321

[18]KAMACI, Z., & ÖZER , P. (2018). Engineering Properties of Eğirdir-Kızıldağ Harzburgitic Peridotites in Southwestern Turkey. *International Journal of Computational and Experimental Science and Engineering*, 4(2), 14–22. Retrieved from https://ijcesen.com/index.php/ijcesen/article/view/62

[19]Arbouz, H. (2024). Study of an Efficient and Environmentally Friendly Germanium-Based CsGeI3 Perovskite Structure For Single and Double Solar Cells. *International Journal of Computational and Experimental Science and Engineering*, 10(1);33-41. https://doi.org/10.22399/ijcesen.250