APPLICATION OF SAWDUST ASH AS FILLER MATERIAL IN ASPHALTIC CONCRETE PRODUCTION

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Abstract

An increase production of wastes from different companies and agricultural areas creates severe surrounding trouble in terms of management and removal in Ethiopia. Utilization of by-products and residue in construction work is an excellent alternative solution in reducing disposal problems. In this research, the application of sawdust ash in asphalt concrete production is investigated as filler material. Physical and chemical tests were investigated for Saw Dust Ash (SDA). Asphalt specimen prepared using basaltic stone dust without sawdust as filler used as a control material. The SDA was partially replaced with 3 %, 6 %, 9 %, and 12 % by amount of basaltic dust. Performance evaluation of combinations was explored with fatigue, tensile strength, and deformation resistances experiment. The outcome pointed that the use of SDA as packing material enhanced the fatigue life and permanent deformation of asphalt concrete with variable temperature. Furthermore, it was identified that the combination with SDA indicated less sensitive to moisture than basaltic dust. Research finding indicated, an optimum value of SDA could be replaced the basaltic dust is 12 % in asphaltic concrete production.

Keywords:

Sawdust ash;
 Disposal problem;
 Partial replacement;
 Fatigue life;
 Permanent deformation.

1 Introduction

Locally available and easily accessible materials are always economically realistic in the asphalt concrete production of road construction. The industrial by-product waste disposal is selected in asphaltic concrete production as filler [1]. Pozzolanic characteristics of filler material convey technical merits to the resulting asphalt concrete with a large amount of cement partial replacement [2].

The application of the materials brings surrounding and economic advantages. Waste substance reprocessing products are the best technique of reducing waste effects [3]. Reprocessing is the way to transform waste substances into new inventions to avoid hazards related with desposing, diminishes the spending of natural materials, and it also minimizes greenhouse gas releases comes from the conventional method of excarding of such wastes [4]. A filler material plays a significant matter on the properties of asphalt concrete. Usually, stone dust, cement, and lime are used as filler materials [5].

Filler material includes those materials which pass 75 μm (No. 200) BS sieve. The crucial part of filler materials are the geometry and composition of the material. Filler geometry can be recognized by size, shape, texture, and angularity. Bitumen and filler interaction is affected by several chemical compounds. The reactivity (calcium compound and water solubility) and the harmful fines (actual clay content and organic content) are the two significant characteristics of these interactions. Filler materials used in the pavement industry are ordinary fillers and the imported filler. As andesite, basalt, caliche, dolomite, granite, volcanic ash, and limestone are categorized as ordinary fillers, whereas fly-ash, furnace slag, and hydrated lime are categorized as imported fillers [6].

Filler materials were initially added to the dense-graded asphaltic concrete mix to fill spaces in between aggregates and minimize the gaps in the mix [7]. Many researchers investigated on the application of different fillers at various paving mixes. Even though packing materials are tiny in size, it has been recognized that filler brings a considerable impact on properties and qualities of asphalt

concrete mixture. Excellent packing of coarse and fine aggregates and filler affords a tough stamina for mix [8]. More filler content incurs well-built pavement characterized to superior asphalt cohesively and superior internal stability. However, excess quantity of filler may reduce the strength of the mix by rising the quantity of bitumen required to coat the aggregates [9].

Sawdust is an organic waste material obtained from the mechanical milling of timber into various shapes and sizes [10]. Its combustion sources the ash. The characteristics of asphalt concrete are enhanced by adding a high amount of Calcium oxide (CaO). The modification of the asphaltic concrete mixed with different percentages of sawdust ash significantly and positively affected the behavior of asphaltic concrete [11].

The sawdust with carbon containing less oxygen could be used to replace the conventional filler in hot mix asphalt by the weight of aggregate. The addition amount of wood sawdust identified based on Marshall properties. Adding carbonized sawdust and replacing HMA reduces the price incurred of filler materials when it is compared with using conventional fillers for asphalt concrete production [12].

Physically, sawdust ash is a lightweight material from its specific gravity of 2.29, whereas it contains calcium oxide, silica, alumina, iron oxide, sulphur oxide, potassium oxide, magnesium oxide, tungsten oxide, and phosphorous oxide chemically as the major constituents of oxides.

Calcium oxide, the meaningful content of SDA and significantly enhances the properties of asphalt concrete. The modification of asphalt concrete mixed by varying the amount of sawdust ash significantly and changes the properties of asphalt concrete [11]. Sodium chloride features an enormous role within the improvement of the properties of bitumen. Sometimes, it is adverse effects on minimizing the strength of the bituminous mixes. The steadiness value of the bituminous mixes decreases gradually with an increase in salt content in bitumen. The penetration value and relative density increases and softening point, flush & fire point, solubility, and ductility of bitumen decrease with increasing salt in pure bitumen, which indicated that the adhesion and cohesion properties of bitumen were reduced with increasing the proportion of salt in bitumen. The tolerable salt limit in the mix varied from zero to five percent [13]. Currently, the quest for cost, pollution, and disappearing of conventional filler material challenges need quick solution in the production of HMA. Therefore, the aim of this study was focused on the evaluation of sawdust ash as part of filler material in asphalt mixtures. An experimental investigation was performed for this research. Moreover, the Marshall property, fatigue life, deformation resistance, and tensile strength resistance tests of mixtures were assessed in this study.

2 Materials and methods

For this study, the basaltic rock of coarse aggregate (CA) and fine aggregate (FA) with desirable strength, hardness, toughness, relative density, and shape were chosen and taken from the Jimma district Ethiopian Road Authority (ERA) quarry site. The mechanical characteristics of aggregates are summarized in Table 1. Bitumen 60/70 penetration grade was taken from Jimma district ERA batch plant. The laboratory results of bitumen are shown in Table 2.

Table 1: Physical characteristics of aggregates.

Physical properties	Test method	CA	FA	Standard value
Aggregate crushing value %	BS 812,104	16.70	-	< 25
Aggregate impact value %	ASTM C 128	14.21	-	< 30
Specific gravity	AASHTO T 84	2.613	2.636	2.4 - 2.6
Flakiness index %	BS 812, 110	24.70	-	< 45
Loss angeles abrasion %	AASHTO T 96	12.60	-	< 30
Fines value %	IS: 2386	90.40	-	N/A

Table 2: Physical characteristics of asphalt.

Property	Test method	Result	Standard value
Penetration, 100 gm, 5 sec at 25 °C	ASTM D-5	63	60 - 70
Ductility, 5 cm/min at 25 °C	ASTM D-113	100	100 +
Specific gravity at 25 °C	ASTM D-70	1.02	1.01 - 1.06
Softening °C	ASTM D-36	49	46 - 56
Flashpoint °C	ASTM D-92	280	≥ 230
Solubility %	ASTM D-2042	99.34	≥ 99
Loss on heating	ASTM D-6	0.04	≤ 0.2

2.1 Fillers

Basaltic stone dust (BSD) and SDA were used as filler material for this research study. Basaltic stone dust is collected from the same quarry site aggregate is taken. The raw SD was collected from Jimma city timber industries. The SDA was obtained from the burnt sawdust at 30 °C with fire. The gradation, plastic index, and specific gravity of BSD and SDA were tested in the laboratory. The experiment outcome is shown in Table 3.

Table 3: Physical characteristics of filler materials.

Sieve size (mm)	Test method	BSD	SDA	Standard value
0.6	AASHTO M-17	100	100	100
0.3	AASHTO M-17	95.6	98.7	95 - 100
0.075	AASHTO M-17	83.5	86.4	70 - 100
Plastic index	AASHTO M-17	0	2.6	≤ 4
Specific gravity	ASTM D-854	2.55	2.549	-

2.2 Course aggregate

In this research, the coarse aggregate used was a crushed stone of basaltic origin. The maximum nominal size of coarse aggregate used for mix was 20 mm. The gradation of coarse aggregate was conducted as per ASTM C-33 specification. The result of grain size distribution of coarse aggregate was shown in Fig. 1.

Fig. 1: Grain size distribution curve.

2.3 Chemical composition of SDA

The chemical compositions of SDA obtained using X-ray diffraction are shown in Table 4. The result indicated, SDA contained the following elemental oxides and compounds: Calcium

pyrophosphate ($\text{Ca}_2\text{H}_2\text{O}_8\text{P}_2$) 38.00 %, Calcite (CaCO_3) 28.90 %, Quartz (SiO_2) 24.20 %, Potassium nitrate (KNO_3) 6.40 %, Sodium Chloride (NaCl) 1.00 %, Carbon graphite 2H (C) 0.60 %, Periclase (MgO) 0.60 %, Potassium Chloride (KCl) 0.20 % respectively.

Table 4: Chemical composition of SDA.

Chemical composition	Content [%]
$\text{Ca}_2\text{H}_2\text{O}_8\text{P}_2$	38.0
CaCO_3	28.9
SiO_2	24.2
KNO_3	6.4
NaCl	1.0
C	0.6
MgO	0.6
KCl	0.2

2.4 Mixture design

Marshall Stability test is carried out to determine the optimum bitumen content. Test specimens are prepared by varying percentages of bitumen from 4.5 % to 6 % by the weight of aggregates with a 0.5 % increment for each variety of fillers. Sample preparation, compaction, and testing were conducted following ASTM D1559 for all specimens. The mixture prepared from basaltic filler with 100 % was named as control. Marshall Stability and flow experiments were conducted, where the cylindrical sample specimen is soaked in water at 60 °C for a time of half-hour so compacted on tangential surface at fixed rate of two-inch/min until the most loads were reached. The governed resistance load and flow value were recorded. The bulk specific gravity and density, theoretical maximum specific gravity and percent air voids were determined for each specimen. In Table 5, the mixture properties of 100 % BSD as filler and 100 % SDA as filler are shown separately. The relation between optimum bitumen content (OBC) and SDA content of the mix are shown in Fig. 2. As it was observed in Fig. 1, the use of SDA in asphalt concrete production as filler raises the OBC as a result of more consumption of the SDA compared to basaltic dust.

Table 5: Marshall properties with BSD and SDA.

Mix properties	BSD	SDA	Standard values
OBC [%]	5.2	5.6	4 - 10
Unit weight [g/cc]	2.31	2.15	-
Air void [%]	4.26	10.12	3 - 6
Stability kN	11.27	8.94	≥ 8
Flow mm	3.63	3.33	2 - 4
VMA [%]	20.91	25.90	≥ 14
VFB [%]	71.60	55.55	65 - 73

Fig. 2: Effect of SDA on OBC.

2.5 Tensile fatigue resistance test

The fatigue resistance test evaluates the fatigue performance of the mix. The fatigue process was assessed in different platforms. In the beginning, failure and fatigue fracture started. Next, as fractures propagated further, and it reduces pavement strength. Lastly, the pavement failure was revealed [14]. A fatigue life of specimens has been quantified with a persistent tension approach with frequent weights of constant amplitude in lined with a diametrical axis of specimen.

A correlation of tensile strain and a number of cycles to failure of individual specimen have been developed. A linear correlation has been registered as the strain was plotted against the numbered cycles to failure, and the fatigue age expectation formulas have been established [15]. The fatigue formulas were established using regression analysis, in the form of Wohler's fatigue expectation ideal in Eq (1)

$$N_f = K_1(\varepsilon_t)^{K_2}, \quad (1)$$

as N_f – numbered cycles to failure; ε_t - acted strain; K_1 and K_2 - coefficients linked to mixture characteristics.

2.6 Tensile strength resistance test

A stripping strength (capacity) of mixtures has been assessed with reducing the loss in tensile strength (TS) after soaking in water for 24 hours heated at 60 °C [16]. For this investigation, the moisture susceptibility of HMA has been evaluated with tensile strength ratio (TSR) test. For this aim, diametrical specimens have been examined in dry and wet situations at temperature of 25 °C. The specimens in wet situations have been kept in a vacuum to grasp the inundation level of fifty to eighty percent. Vacuum inundated specimens have been retained at eighteen degree centigrade cooler for sixteen hours and then kept at sixty degree centigrade water tank for twenty four hours. All specimens have been brought to fixed temperature, and the tensile strength has been recorded on dry and wet specimens. A sample has been taken out of the water tank. The depth of sample has been estimated, and placed in the testing equipment on its side. Brace bearing strips have been kept between the samples and the loading braces. A pressure has been acted to the sample. By pressing the loading braces together at a fixed speed of 50.8 mm/min, as per Eq (2)

$$S = \frac{2P}{\pi Dt}, \quad (2)$$

as S - tensile strength, kN/m²; P - acted vertical load (kN); t – depth of sample, m, D - sample diameter, m. The TSR has been estimated by Eq (3)

$$TSR = 100 \cdot \left(\frac{S_{wet}}{S_{dry}} \right), \quad (3)$$

as S_{wet} - tensile strength of wet sample; S_{dry} - tensile strength of dry sample.

2.7 Permanent deformation tests

The experiment was carried out to assess the ability of mixture to withstand permanent deflection are the Marshall stability, static creep, dynamic creep, and the wheel-tracking tests [17]. For this research, the capacity to withstand permanent deflection of SDA mixtures has been investigated by dynamic creep and static creep tests accordingly. A static creep test is applied to quantify the creep deflection of dimetrical samples under a point stationary load as a function of time. The deflection results have been quantified by linear variable differential transducer. An experiment has been carried out for all mixtures with desirable bitumen content. Since the hazard of permanent deflection has been higher, a uniaxial pressure of 0.4 MPa, the temperature of 40 °C and the load duration of 10⁴ s were chosen. The dynamic creep experiment actes a frequent pulsed uniaxial stress on an asphalt sample and quantifies deflections in one direction with a linear variable differential transducers. The dynamic creep test has been carried out with dynamic stress of 100 kPa at temperature of 40 °C for an hour. For the specific experiment, the specimen prepared and kept in the equipment under wet stress of ten kilo Pascal for six hundred seconds. Then, the wet stress has been taken out, and the pressure of 200 kPa has been acted for 10⁴ cycles.

3 Results and discussion

The samples made from basaltic stone dust (BSD) and sawdust ash fillers showed that the values of unit weight increases to some extent then decreases. The reason behind it is as the content of bitumen increases in the mixture; it fills the voids and increases its unit weight. The sawdust ash specimen revealed a higher percentage of air voids (10.12 %) and low unit weight (2.15 g/cc) in comparison, basaltic crushed stone dust. Even though the stability, VMA, and flow are satisfactory, the air void and VFB at 100 % SDA replacement were not satisfied with the standard. This could be achieved by replacing basaltic crushed stone dust with SDA in 3 %, 6 %, 9 %, 12 % and 15 % by weight of BSD as shown in Table 7. The result indicated that the SDA couldn't satisfy the ERA standard specification when it is replaced basaltic stone dust beyond 12 % in the production of asphaltic concrete.

Table 7: Effect of SDA on Marshall properties mixture.

Mixture property	Replacement amount of SDA						Standard value
	0 %	3 %	6 %	9 %	12 %	15 %	
Unit weight	2.31	2.27	2.25	2.22	2.21	2.18	-
Air void	4.26	4.53	4.72	4.89	5.12	6.26	3 - 6
Stability	11.27	10.99	10.70	10.51	10.36	10.22	≥ 8
Flow	3.63	3.49	3.35	3.21	3.07	2.68	2 - 4
VMA	20.91	21.15	21.39	22.03	22.86	23.28	≥ 14
VFB	71.60	70.09	69.58	68.07	66.55	63.43	65 - 73

3.1 Tensile fatigue resistance

Outputs of the fatigue resistance test have been shown graphically in Fig. 3 and 4. The graphs have modeled with average outputs of individual specimen of separate strain level, and the results revealed the normal correlation of the initial tensile strain and the fatigue age of mixture. The sample contains SDA showed a greater numeral of cycles to fail than that of BSD. It is possible to easily understand from the figures the load cycles to failure have been increased when the quantity of SDA increased in the mix. Because of higher percentage of OBC, SDA mixes affords more elastic properties marking an improved fatigue age, reliable with greater pulse counts in fatigue resistance test. The mix of greater variability absorbs and distributes stresses formed by fatigue loading, which might create delay of affects of asphaltic concrete.

The fatigue life of 3 %, 6 %, 9 %, and 12 % sawdust ash of mixtures at 15 °C were 7468, 8200, 8959 and 9562 cycles to failure were: 1.1, 1.2, 1.3, and 1.4 times respectively relative to that of basaltic dust mix. In the same way, when temperature is increased to 20 °C, the fatigue life of all samples reduced. This behavior has been because of greater susceptibility of bitumen to temperature, as identified by former researchers [18 - 20]. The mixtures with SDA revealed greater susceptibility to temperature rise as amount of OBC is greater in the mix in comparison to basaltic mixture. The fatigue formulas have been shown in Table 8 for each combination in the mixture at 15 °C and 20 °C. As shown in Fig. 9 (a) and (b), it could be revealed that all outputs of K_1 and K_2 has been increased as the amount of sawdust ash increased in the mix, causing an increase of failure of asphaltic concrete.

Fig. 3: Mixtures fatigue behavior at 15 °C.

Fig. 4: Mixtures fatigue behavior at 20 °C.

3.2 Tensile strength resistance

A tensile strength resistance of mixes under dry and wet situations of samples has been given in Fig. 5. It has been indicated that the result of tensile strength of wet mixes were lesser when compared with that of dry mixes. It might happen due to the existence of water reasons a decrease in bondage between bitumen and aggregate, and hence the resistance of asphaltic concrete of specimens decreases under traffic loading. Similarly, it could be detected that the loss in tensile strength of sawdust preserved mixtures as a result of moistness has not been higher than basaltic mixes. SDA improves the bondage between bitumen and aggregate, that prevents water to dislodge bitumen from the surface of aggregate. The results of TSR of specimens by varied the amount of SDA has been shown in Fig. 6. It also indicated, the SDA has considerably enhanced the values of TSR dry and wet mixes, which directed to well resistance to moisture susceptibility. All TSR results of SDA preserved mixes have been relatively more than eighty percent. Adding SDA as 3 %, 6 %, 9 %, and 12 % to the mix has been increased TSR by 1.43 %, 2.86 %, 4.67 %, and 6.64 %, correspondingly, relative to basaltic dust mixes. A specimen having 12 % of SDA revealed the greatest results of TSR, which confirmed that SDA might be well in preventing moisture damage.

Fig. 5: Tensile strength of dry and wet samples.

Fig. 6: TSR of specimens.

3.3 Permanent deformation

Experimental results of static creep and dynamic creep were shown in Fig. 7 and 8 respectively. The values of static creep indicated that specimens lacks SDA ensured greater permanent deformation than that of having 3 %, 6 %, 9 % and 12 % of SDA in the mix; the experiment revealed that the values of permanent deformation is decreased by 6.89 %, 15.33 %, 23.74 %, and 27.84 % correspondingly. Also, the dynamic creep test depicted that adding SDA to the mix reduced the values of permanent deformation. Adding 3 %, 6 %, 9 % and 12 % of SDA in the mixes resulted decrease in permanent deformation by 8.58 %, 16.14 %, 23.17 % and 30.75 % respectively. The experiment revealed the acceptable amount of SDA to decrease permanent deformation could be 12 % as compared to basaltic dust.

Fig. 7: Deformation behavior with time.

Fig. 8: Deformation behavior with cycle.

Fig. 9: Coefficients of mixture properties.

Table 8: Fatigue prediction equations of mixtures.

SDA (%)	0	3	6	9	12
N_f @ 15°C	$3.0 \cdot 10^6 \varepsilon^{-1.31}$	$5.6 \cdot 10^7 \varepsilon^{-1.52}$	$6.6 \cdot 10^8 \varepsilon^{-1.68}$	$5.2 \cdot 10^9 \varepsilon^{-1.86}$	$1.0 \cdot 10^{10} \varepsilon^{-2.27}$
N_f @ 20°C	$9.0 \cdot 10^5 \varepsilon^{-1.37}$	$6.9 \cdot 10^6 \varepsilon^{-1.68}$	$6.9 \cdot 10^7 \varepsilon^{-2.95}$	$7.3 \cdot 10^8 \varepsilon^{-2.20}$	$9.8 \cdot 10^9 \varepsilon^{-2.46}$

3.4 Chemical composition of SDA

The high content of ($\text{Ca}_2\text{H}_2\text{O}_8\text{P}_2$) improves of the stiffness or the moisture affect of asphaltic concrete mixture. Presence of quartz (SiO_2) in the ash indicates the materials produce a mixture with an excellent permanent deformation and fatigue cracking resistances. The presence of calcium carbonate in the ash increase the fatigue life of asphaltic concrete by reducing the effect of rutting potential and moisture damage potential [20, 21]. Existence of calcite in SDA reduces shrinkage effect, increase impact, and improve the surface finish of the pavement. The presence of Carbon graphite 2H(C) in the ash has the advantages to strain-stress self-monitoring, traffic control, border control, and structural vibration control. It also enhances the tensile strength and long-range connecting effect of asphalt.

4 Conclusion

The basaltic crushed stone dust can be replaced with the optimum value of 13 % SDA as filler material in asphalt concrete production as per ERA standard specification. The result obtained from indirect tensile strength and fatigue tests revealed that SDA could be used as filler up to 12 %. Replacing basaltic crushed stone dust with 100 % SDA led to higher absorption of bitumen. Replacing basaltic dust by 12 % of SDA inhaned the fatigue life of asphaltic concrete. As temperature increased, the fatigue life of samples reduced. This is happened from the high susceptibility of asphaltic concrete to temperature. Static creep and dynamic creep results revealed, addition of SDA could decrease permanent deformation in the mixes. High concentration of calcium carbonate in the ash reduces rutting and moisture damage potentials.

References

- [1] ANTIOHOS, S. - MAGANARI, K. - TSIMAS, S.: Evaluation of blends of high and low calcium fly ashes for use as supplementary cementing materials. *Cem Concr Compos.* 27(3), 2005, pp. 349-356.
- [2] HOSSAIN KMA: Blended cement using volcanic ash and pumice. *Cem Concr Res.* 33 (10), 2003, pp. 1601-1605.
- [3] HASSAN, Y. - AHMED AMO AND AAM: Effect of Using Waste Cement Dust as a Mineral Filler on the Mechanical Properties of Hot Mix Asphalt. *Ass Univ Bull Environ Res.* 9(1), 2006, pp. 51- 60.
- [4] GROSSE, F.: Is recycling part of the solution? The role of recycling in an expanding society and a world of finite resources. *Sapiens*, 3(1), 2010.
- [5] RETARDANT, I. F.: Effect of Fillers. Packag (Boston, Mass), 2009, pp. 5-7.
- [6] Cooperative N. Research Results Digest 357 Test methods and specification criteria for. 2011.
- [7] Aggregate Properties and the Performance of Superpave-Designed Hot-Mix Asphalt. Aggregate Properties and the Performance of Superpave-Designed Hot-Mix Asphalt, 2005.
- [8] ZULKATI, A. - DIEW, W. Y - DELAI, D. S.: Effects of fillers on properties of asphalt-concrete mixture. *J Transp Eng.* 138(7), 2012, pp. 902-910.

- [9] KANDHAL, P. S. - LYNN, C. Y. - PARKER, F.: Characterization tests for mineral fillers related to performance of asphalt paving mixtures. *Transp Res Rec.* 1638, 1998, pp. 101-110.
- [10] MARTHONG, C.: Sawdust Ash as partial replacement of Cement. *Int J Eng Res Appl.* 2(4), 2012, pp. 1980-1985.
- [11] OSUYA, D. O. - MOHAMMED, H.: Evaluation of sawdust ash as a partial replacement for mineral filler in asphaltic concrete. *Ife J Sci.* 19(2), 2017, pp. 431- 439.
- [12] YASANTHI, G. N. - M.RENGARASU, R. - BANDARA, T. W.: Study on the Performance of Waste Materials in Hot Mix Asphalt Concrete. *Am Sci Res J Eng Technol Sci.* 23(1), 2016, pp. 252-267.
- [13] MD. SHARIFUL ISLAM: Effect of Sodium Chloride on Properties of Bitumen. *J Traffic Transp Eng.* 7(2), 2019, pp. 85–95.
- [14] ARABANI, M. - AZARHOOSH, A. R.: The effect of recycled concrete aggregate and steel slag on the dynamic properties of asphalt mixtures. *Constr Build Mater.* 35, 2012, pp. 1-7.
- [15] MOGHADAS NEJAD, F. - AZARHOOSH, A. R. - HAMED, G. H. - AZARHOOSH, M. J.: Influence of using nonmaterial to reduce the moisture susceptibility of hot mix asphalt. *Constr Build Mater.* 31, 2012, pp. 384-388.
- [16] VISHAL, U. - GOLI, A. - CHOWDARY, V.: Comparison of AASHTO T283 and Moisture Induced Sensitivity Tester Conditioning Process on the Moisture Resistance of Bituminous Concrete Mixtures, 2018.
- [17] ARABANI, M. - MOGHADAS NEJAD F. - AZARHOOSH, A. R.: Laboratory evaluation of recycled waste concrete into asphalt mixtures. *Int J Pavement Eng.* 14(6), 2013, pp. 531–539.
- [18] TAYEBALI, A. A. - ROWE, G. M. - SOUSA, J. B.: Fatigue response of asphalt-aggregate mixtures. *Asphalt Paving Technology: Association of Asphalt Paving Technologists-Proceedings of the Technical Sessions*, Vol. 61, 1992, pp. 333-360.
- [19] NCHRP: Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, Appendix II-1: Calibration of Fatigue Cracking Models for Flexible Pavements. *Transp Res Board Natl Res Counc.* 2004, p. 311.
- [20] MOGHADAS NEJAD, F. - GERAEE, E. - AZARHOOSH, AR.: The effect of nano calcium carbonate on the dynamic behaviour of asphalt concrete mixture. *Eur J Environ Civ Eng.* 8189, 2018, pp. 1-10.
- [21] REMISOVÁ, E. - LIU, G. – KOMAČKA, J. – WU, S. – XIAO, Y. – HOLÝ, M.: Rheological Properties of Bitumens from the Perspective their Chemical Composition. *Civil and Environmental Engineering*, 15(2), 2019, pp. 174–182.