New concept of sustainable road structure with RAP binder course using bio-agent

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ABSTRACT

Growing demand on paving materials requires application of recycling materials. In some countries Reclaimed Asphalt Pavement (RAP) is commonly used for construction of road pavements structural layers. Often limitations are applied in order to amount and type of recycled materials.

In this paper a new, innovative concept of asphalt structure for local roads is proposed. In such structure each layer includes bio-origin material or materials from recycling. Research work conducted under the "Use of eco-friendly materials for a new concept of Asphalt Pavements for a Sustainable Environment" (APSE) project consist of complex analysis of opportunities for application into each structural layer material from recycling, including asphalt- origin materials. A proposed new structure will composed of surface layer with bioethanol modified eco-asphalt. For interlayer increased amount of RAP is going to be used due to application of bio-agent rejuvenating binder property. In non-asphalt base layer material from infrastructure demolishing will be used, including demolished cement concrete.

In this paper test result of asphalt mixes composed with using of the bio-agent and RAP are presented. It was proofed that higher than typical amount of RAP can be applied for the production of asphalt mixture in traditional asphalt mix plant not equipped with double barrel. Results proofed that bio-agent serves the role of rejuvenator in asphalt mixture and allows for either application of higher RAP content of production of the mixture in lowered technological temperature.

Keywords: Additives, Environment, Reclaimed asphalt pavement (RAP) Recycling, Rejuvenators

1. NEW CONCEPT OF SUSTAINABLE ROAD STRUCTURE

Growing demand on paving materials requires application of recycling materials. In some countries Reclaimed Asphalt Pavement (RAP) is commonly used for construction of road pavements structural layers. Material from milled asphalt pavement can be successfully recycled and used for construction of new pavement, in hot, warm or cold technology. Recycling process can be accomplished on-site or in remote location, in asphalt plant. Production of new asphalt mixture with RAP in plant allows to better control overall mixture quality, materials proportioning and improves material homogeneity [1]. Cold recycling technology is accomplished with application of bituminous emulsion or foamed bitumen. Due to the technological limitations, this technology is typically used for construction of lower structural layers of road: subbases with mineral-cement-emulsion or subbases with foamed bitumen [2].
Currently, according to the sustainable policies, the most feasible solution would be utilization of all obtained RAP for construction of new asphalt pavement. Additional benefit from such solution are financial savings and improved ecological impact due to decreased demand for new material, savings on transportation etc. Main reason for application of milled asphalt mixture from recycling is decreased need for new material (aggregate and bitumen) for production of new asphalt mixtures [3].
Often limitations are applied in amount and type of recycled materials. To save energy, reduce the consumption of materials and diminish carbon impact it is possible to use new vegetable origin binders where synthetic and petro-chemical products are partially replaced with plant-based products [4,5]
Vegetable origin binder may change viscosity of the binder allowing for the lower asphalt mixture production temperature [6,7]. Once vegetable oils and methyl esters of fatty acids, obtained by transesterification of these oils, are used as bitumen fluxes, hardening of the binder after application is reached not by evaporation of the solvent to the atmosphere (like for the typical cutbacks) but by crosslinking of the unsaturated fatty acids as a result of its reaction with oxygen. When acting as a flux agent, they replace the use of conventional petro-chemical products which are flammable and leads to the evaporation to the atmosphere of volatile organic compounds (VOCs) [5,8].
Gawel et al. [6,7] proposed solutions to the oxidation conditions for rapeseed and linseed oils and the corresponding methyl esters, in order to obtain environmentally-friendly bitumen fluxes. New generation of bituminous binders fluxed with rapeseed oil methyl esters with sycatives exhibit lower consistency during asphalt mixture production process and rebuilded consistency during pavement exploitation, as a result of polymerization reaction. [9].
In this paper a new, innovative concept of asphalt structure for local roads is proposed. In such structure each layer includes bio- origin material or materials from recycling. Research work conducted under the "Use of eco-friendly materials for a new concept of Asphalt Pavements for a Sustainable Environment" (APSE) [10] project consist of complex analysis of opportunities for application into each structural layer material from recycling, including asphalt-origin materials:

- A proposed new structure will composed of surface layer with bioethanol modified eco-asphalt.
- For interlayer, increased amount of RAP is going to be used due to application of bio-agent rejuvenating binder property.
- In non-asphalt base layer material from infrastructure demolishing will be used, including demolished cement concrete.

2. OBJECTIVES AND RESEARCH APPROACH

In the research presented in this paper analysis were conducted to determine the possibility of application higher than typical RAP content in asphalt pavements but with traditional technologies (without an additional RAP heating system). From one side, increased amount of RAP may cause the necessity to rejuvenate aged bitumen, while aged bitumen may also require higher production temperatures. In such case a solution can be application of bitumen fluxed with bio-origin agent, allowing to decrease asphalt production temperature. In parallel, chemical reaction in bio-agent and aged bitumen, occurring in time, provides rejuvenation of technical properties of asphalt mixture.
The objective of this paper was to present research approach and test results for asphalt mixes composed with bio-agent and RAP. Main objective was to verify that higher than typical amount of RAP can be applied for the production of asphalt mixture in traditional asphalt mix plant not equipped with double barrel system. In Poland, limit for RAP application directly to the mixer is 20% while in the case where double barrel system is utilized this limit is elevated to 30%. In this research it was assumed that 30% of RAP will be used in the technology without application of an additional RAP heating system. It was also verified that bio-agent serves the role of rejuvenator in asphalt mixture and allows for either application of higher RAP content or production of the mixture in lowered technological temperature.
Schematic of asphalt concrete variations being tested is shown in fig. 1 for AC16W with different binder type, application of RAP and bio-agent.

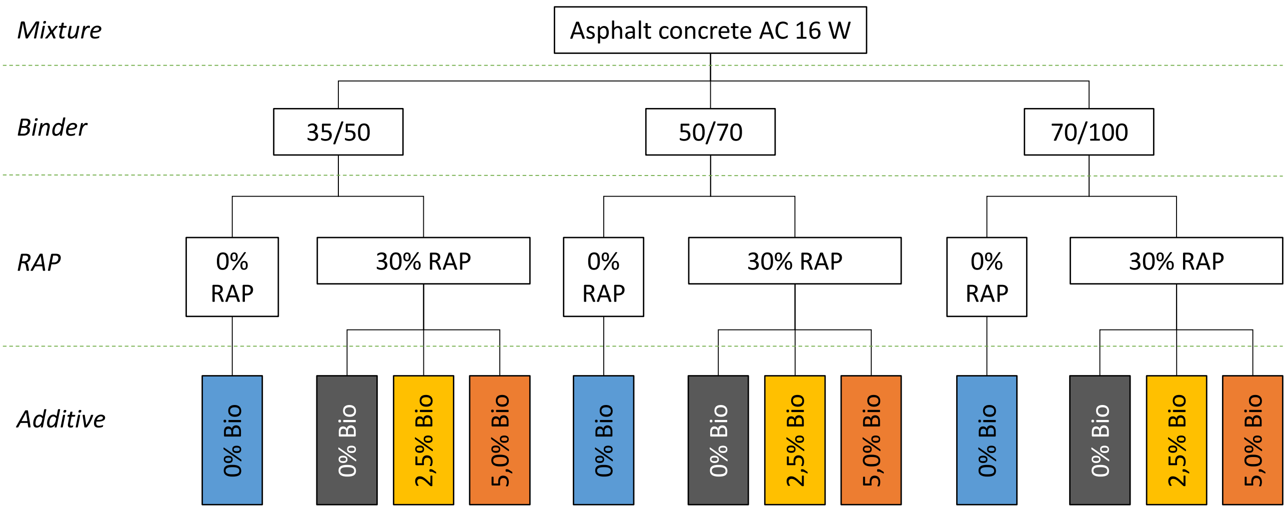

Figure 1: Research approach

3. MATERIALS AND SAMPLE PREPARATION

3.1 Bio-fluxed binder – production and properties

Rapeseed oil methyl esters (RME) were used to produce ecological bitumen fluxes. Lower susceptibility of rapeseed oil for oxypolymerization reaction, as compared to the drying oils, implies the necessity of its oxidation in presence of the reaction initiator in order to receive product which would be possible to be used as a bitumen flux. Oxidation of RME was conducted in room temperature (20-25°C) in presence of cobalt catalyzer and cumene hydroperoxide serving as initiator of polymerization reaction. Fluxing bio-agent was obtained by mixing of RME and cobalt catalyzers in amount of 0,1% m/m and then by mixing for two hours in column reactor at 20°C. A picture of such laboratory reactor for continues oxidation of bio-agent is shown in fig. 2.

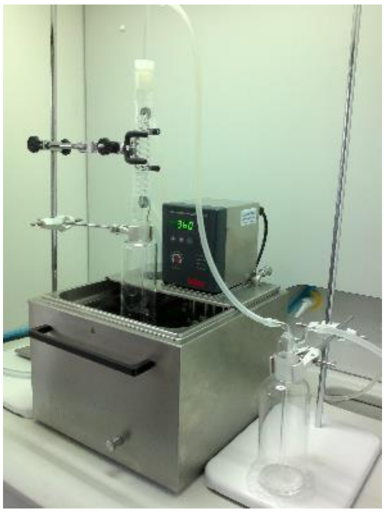

Figure 2: Laboratory reactor for continues bio-agent oxidation process

Three different road bitumens (35/50, 50/70 and 70/100) modified with bio-agent at two levels (2,5% and 5,0% m/m) were used in this study. Bitumens were heated to the temperature grater by 80°C from bitumen softening temperature and bio-agent agent was added. Such samples were then mechanically mixed until homogenous blend was obtained. This modified binder was tested for binder properties as well as was used during asphalt mixtures preparation. Properties of bitumens used in this study are shown in table 1.

Table 1: Binder properties

Binder	Softening temperature R&B, °C	Complex modulus at 20°C, MPa	Phase angle at 20°C, °
35/50	54,5	7,97	30,5
35/50 + 2,5%	46,5	1,56	51,8
35/50 + 5,0%	40,0	0,48	62,2
50/70	49,0	4,74	41,5
50/70 + 2,5%	42,0	1,03	61,1
50/70 + 5,0%	35,5	0,27	70,5
70/100	46,5	4,08	44,3
70/100 + 2,5%	39,5	0,72	65,3
70/100 + 5,0%	33,0	0,17	74,0

Based on the binder properties shown in Table 1 it can be noticed that increased amount of bio-agent in bitumen results in decreased consistency. With bio-agent used in higher amount (5,0%), softening temperature decreased by 14±1°C while with lower amount of bio-agent (2,5%), temperature decreased by 7±1°C, independently from the bitumen type. Bitumen stiffness was also reduced, since complex modulus decreases and phase angle increases, as tested at 20°C.

3.2 Design and characterization of asphalt mixtures with RAP

Two asphalt mixtures for binder layer, with maximum aggregate size of 16 mm, were designed. As a reference mixture, asphalt concrete for binder layer AC 16W was used. This reference mixture was produced with typical (as per Polish standards of General Directorate for National Roads and Motorways WT-2) bitumen 35/50 (black curve shown in fig. 3). For the right comparison, bitumen type was changed without correction in mixture compounds and proportions. Mixture with reclaimed asphalt pavement (RAP) is shown in fig. 3 (dashed red curve). This mixture was designed with following assumptions:

- constant amount of air voids (Vm) with acceptable tolerance of ±0,3% as compared to the reference sample,
- constant amount of total bitumen (B),
- closed gradation curves.

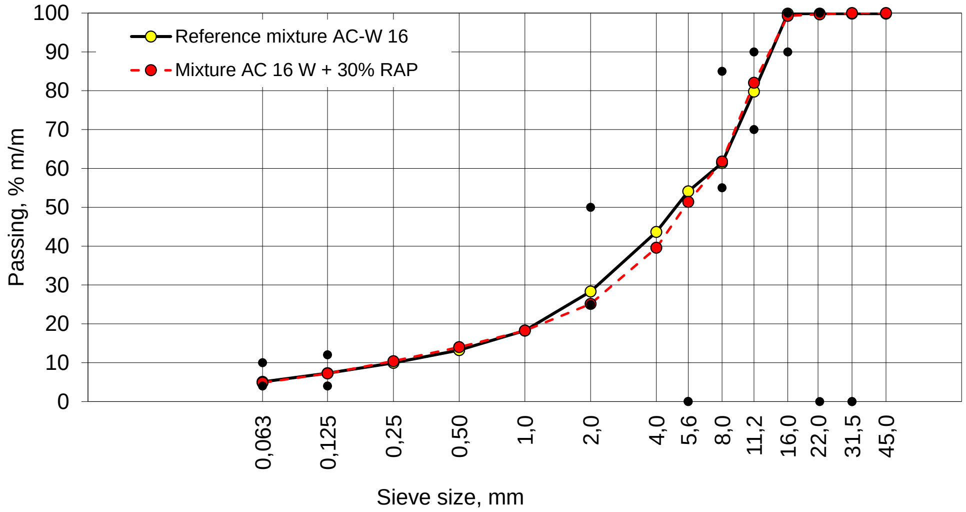

Figure 3: Gradation of reference asphalt mixtures and asphalt mixture contains 30% of RAP

Basic characteristic of mixtures tested in this this study is shown in tab. 2.

Table 2: Characteristic of asphalt mixtures

Properties	Units	Reference mixture AC-W 16	Mixture AC 16 W + 30% RAP
Lime filler content	%	3	2
Fine aggregate content	%	30	15
Coarse aggregate content	%	67	53
Aggregate form RAP	%	0	30
Whole binder content	%	4,6	4,6
Virgin binder	%	4,6	3,1
Binder form RAP	%	0	1,5
Binder replacement factor	%	0	32

4. RESULTS AND DISCUSSION

4.1 Influence of bio-agent on asphalt mixture compaction process

In order to study asphalt mixture compactability, reference samples and asphalt mixtures with RAP were prepared in Marshall compactor with 2x75 blows for each sample, according to *EN 12697-30 Bituminous mixtures. Test methods for hot mix asphalt. Specimen preparation by impact compactor*. Compaction level was determined based on the air voids determination according to *EN 12697-8 Bituminous mixtures. Test methods for hot mix asphalt. Determination of void characteristics of bituminous specimens*. Reference asphalt mixtures AC 16W exhibits same (4,3±0,1%) air voids content, as shown in fig. 4-6 for mixtures with various binder type. During compaction all samples demonstrates similar temperature of 135±5°C. It can be observed that for tested mixtures binder type does not influence compactability. Mixtures with RAP were designed based on the reference sample however in total blend they contain 30% of aggregate from RAP (refer to tab. 2). Mixtures with RAP exhibit comparable with reference samples air voids content (4,3±0,3%).
In those mixtures influence of bitumen type on the compactability can be noticed. Mixture with hardest bitumen 35/50 (shown in fig. 4) exhibit lowest compaction level (V_m = 4,6%) while asphalt with softer binder (with highest penetration of 70/100) presents compaction with Vm=4,0%, below the expected 4,3% level (as shown in fig. 6). Those observations are most likely related to consistency of binder in RAP and stage of its bendability with fresh (virgin) bitumen.
Once compaction of asphalt mixtures with bio-agent is analyzed, it can be noticed that bio-agent application results in better mixture compaction (3,0-3,3% of air voids). Increment of bio-agent content in asphalt mixture does not effects compaction, except asphalt with softest (70/100) bitumen (fig. 6). Based on the compaction of mixtures with RAP as well as with RAP and bio-agent it can be concluded, that design of such mixes should include expected application of flux in order to obtain desired air voids content (compaction level).

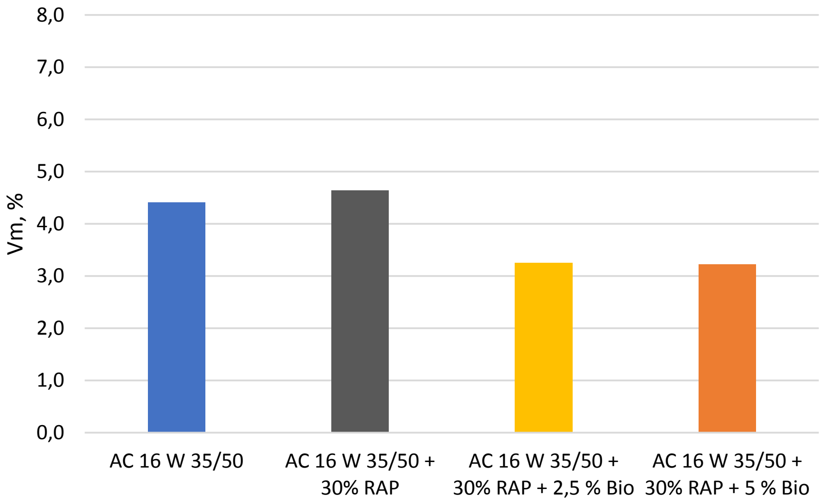

Figure 4: Air void content in asphalt concrete with 35/50 bitumen

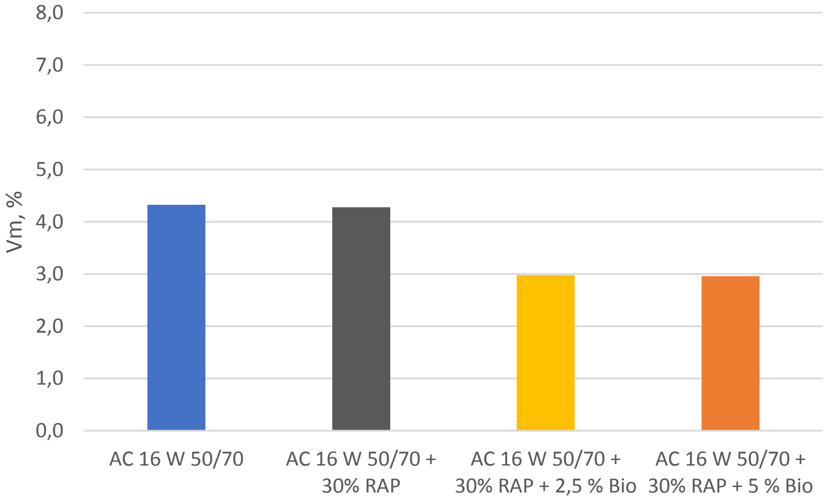

Figure 5: Air void content in asphalt concrete with 50/70 bitumen

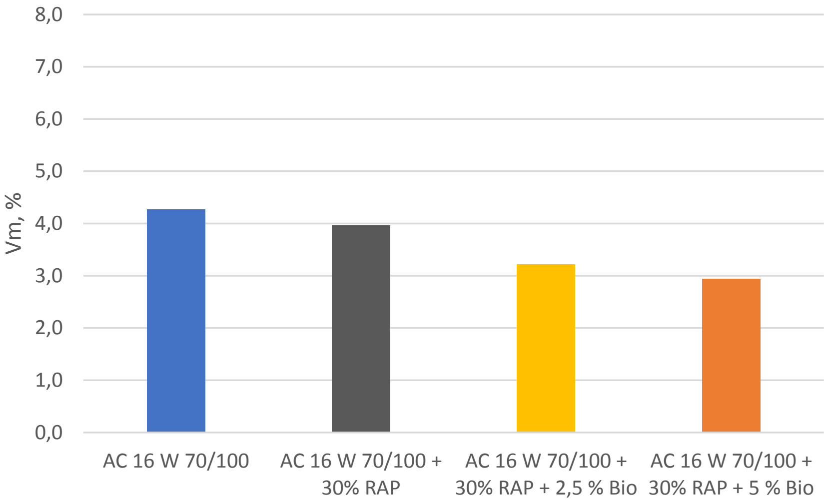

Figure 6: Air void content in asphalt concrete with 70/100 bitumen

4.2 Stiffness of asphalt mixture with RAP and bio-agent

Stiffness tests have been conducted as indirect tension tests on cylindrical specimen (method C according to European Standard *(EN 12697-26:*2012 *Bituminous mixtures. Test methods for hot mix asphalt. Stiffness))*. Marshal-prepared specimens were conditioned and tested at 20°C.
Based on the stiffness test results (shown in fig. 7-9) it can be noticed that bitumen type influence stiffness of the reference mixture, as expected. Highest stiffness was noticed for mixture with bitumen with lowest penetration of 35/50. In asphalts containing 30% RAP (marked in black color on fig. 7-9) stiffness increase can be noticed as compared to reference mixes. Depending on the penetration of the bitumen used, following increase in stiffness was obtained: 10% for asphalt with 35/50 bitumen (fig. 7), 20% for asphalt with 50/70 bitumen (fig. 8) and 30% for asphalt with 70/100 bitumen (fig. 9).
Once influence of bio-agent on asphalt concrete is analyzed, it can be concluded that addition of 2,5% of bio-agent reduces stiffness for about 40%, independently on bitumen type used. Increase of bio-agent content from 2,5% to 5,0% results in additional reduction of stiffness by 10% as compared to asphalt mixture with RAP but without bio-agent incorporated. Finally, it can be noticed that application of bio-agent as a flux to asphalts with RAP allows to eliminate negative phenomenon of stiffness increase caused by application of aged bitumen from RAP.

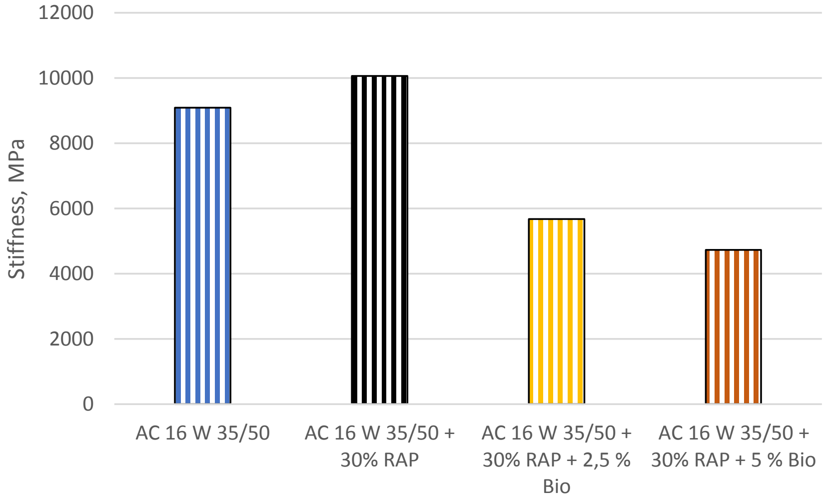

Figure 7: Stiffness (IT-CY) of asphalt concrete with 35/50 bitumen

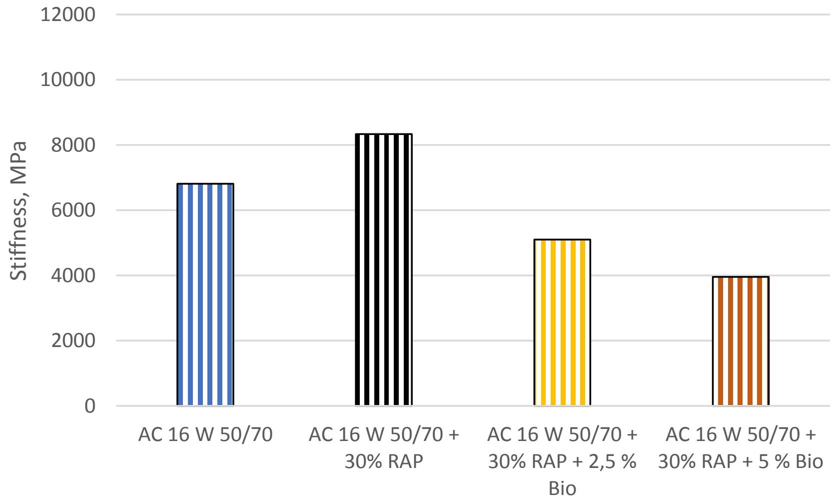

Figure 8: Stiffness (IT-CY) of asphalt concrete with 50/70 bitumen

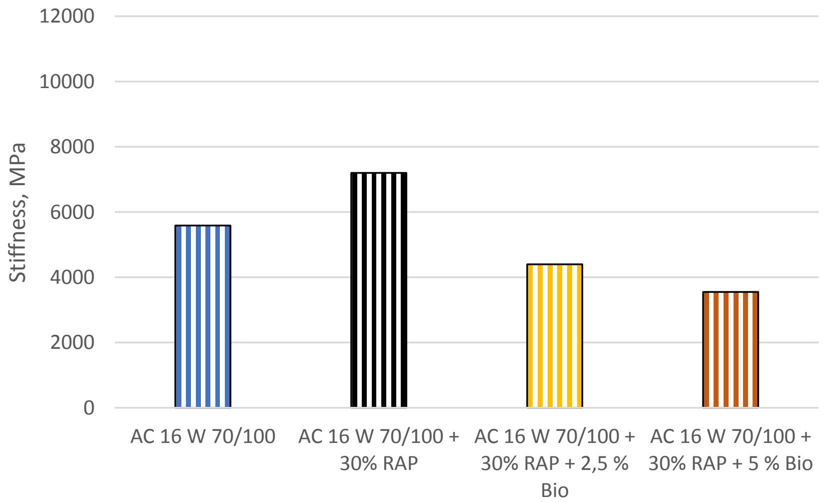

Figure 9: Stiffness (IT-CY) of asphalt concrete with 70/100 bitumen

5. CONCLUSIONS

Based on the conducted tests and analysis following conclusions can be drawn:

- Vegetable-based additives can be used in production of asphalt mixtures, especially to the mixes containing reclaimed asphalt pavement (RAP). Vegetable-based additives derived from RME presents good blendability with bitumen binders, are ecological and comes from renewable resources. Application of renewable materials as well as materials from recycling is with-line with the current sustainable policies observed in European Union. Such solutions protects natural resources.
- Bio-agent causes better capability for quick mixing of asphalt mixture compounds and improves compaction of asphalt mixtures containing RAP. Those phenomenon's are caused by improved blendability of fresh (virgin) bitumen with RAP-origin bitumen.
- Design and optimization of asphalt mixtures should include flux application. Bio-agent supports reaching of the desired air voids content and stiffness level. It can be summarized, that application of bio-agent as a flux incorporated to the asphalt mixtures with RAP allows to eliminate undesired effect of mixtures over-stiffness due to presence of aged bitumen from RAP.

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