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UTICAJ PRIMENE SITNOG AGREGATA OD RECIKLIRANOG BETONA NA KARAKTERISTIKE ASFALTNIH MEŠAVINA

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Rezime:

Cilj ovog rada je procena mogućnosti upotrebe sitnog agregata od recikliranog betona (RCA) u asfaltnim mešavinama. Eksperimentalna ispitivanja su obuhvatila projektovanje i ispitivanje četiri asfaltne mešavine sa delimičnom zamenom sitnog (0/4 mm) prirodnog agregata recikliranim, u količini od 0% (etalon), 15%, 30% i 45%, maseno. Sve asfaltne mešavine su projektovane za noseće slojeve kolovozne konstrukcije. Modul krutosti asfaltnih mešavina sa recikliranim agregatom niži je u odnosu na kontrolnu mešavinu. Dodatak sitnog RCA nema bitan uticaj na otpornost asfaltnih mešavina na dejstvo vode i kreće se u granicama od -2.4% do +1.7% u odnosu na kontrolnu mešavinu. Otpornost na trajnu deformaciju se povećava sa dodatkom do 30% sitnog RCA.

Ključneriječi:asfalt, recikliraniagregat, krutost, dejstvovode, trajnadeformacija.

INFLUENCE OF FINE RECYCLED CONCRETE AGGREGATE ON THE PROPERTIES OF ASPHALT MIXTURES

Abstract:

The objective of this paper was to assess the possibility of using fine recycled concrete aggregate (RCA) in asphalt mixtures. The experimental research included four asphalt mixtures with partial natural aggregate substitution by fine RCA (0/4 mm), in the amount of 0% (control mixture), 15%, 30% and 45%, by mass. All asphalt mixtures were designed for the base course. The stiffness modulus of asphalt mixtures with RCA was lower compared with the control mixture. The use of fine RCA had no significant influence on the water sensitivity and ranged from -2.4% to +1.7% relative to the control mixture. Resistance to permanent deformation increases with the addition of up to 30% fine RCA.

Keywords: asphalt, recycled aggregate, stiffness, water sensitivity, permanent deformation.

1. INTRODUCTION

In the last two decades the world tendencies are turned to reduction of environmental pollution and exploitation of natural aggregates byusing recycled concrete aggregate(RCA) [1-2]. Researchespublished so far have shown that recycled concrete has been used as coarse aggregate for embankments, for the unbound base and sub-base layers in road pavement construction and as a component in cement concrete mixtures.Although, fine recycled concrete aggregate makes 30% to 60% of produced RCA, it was rarely applied because of the high content of very fine particles (filler). Having in mind that fine particles present an obligatory component of asphalt concrete mixtures, it should be expected that the application of both fine and coarse RCA in these mixtures is possible.

RCA produced by milling of old concrete, consists of natural aggregate combined with residual cementitious mortar. The presence of mortar,generally more porous than natural aggregate, influences degradation in the properties of RCA compared to natural aggregates such as: higher water absorption, lower strength, lower density and abrasionresistance [3-5]. Nevertheless, when applied in asphalt concrete production, RCA shows some advantages. Thepresence of residual cementitious mortar makes the surface texture of the RCA exceptionally rough, with sharp edges andfavorably shaped particles. These properties are result of the crushing technology of concrete in production of RCA, contributing to theinteraction and higher surface friction between the aggregate particles. However, the main advantages of possible RCA application are based onthe principles of sustainable development: waste quantities reduction, aesthetic impact on the environment, preservation of natural resources, collection of metal debris during concrete recycling and reduction of C&D waste disposal costs.

Water resistance presents one of the most important tests for asphalt mixtures with recycled concrete aggregates, due to the porosity of this type of aggregates. The importance of this condition is proved by the number of the experiments performed on this subject. Pasandini and Perez [6] presented a thorough review of the waterresistance test results in these kinds of asphalt mixtures. Most of the tests were conducted on the mixtures where both fine and coarse natural aggregate were partially replaced with RCA. Results presented by Shen and Du [7], Perez et al. [8], Bushal and Wen [9] and Mills-Beale & You [10] show that with increase of the RCA content sensitivity of these mixtures to water increases.

Permanent deformation presents one of the most important deterioration mechanisms in flexible road constructions [11]. Results gained in dynamical creep test, conducted by Wong et al. [12], Arabani & Azarhoosh [13] and Arabani et al.[14], show that asphalt mixture containing only fine recycled aggregates (≤ 4.75 mm) had higher permanent deformation resistance than control mixture made with natural aggregate.

Stiffness of asphalt mixtures presents their basic property for determination of the response of the road structure (both stress and strain) to the traffic loads, during the design process. Similarly, asstiffnessdescribes the ability of one asphalt layer to transfer the loads to lower layers, deformation levels at the contact of two different layers are defined for different load levels, and therefore indirectly influence development of the fatigue induced cracks [15]. Higher values of stiffness make the placing of thinner asphalt layers possible, lowering costs of construction. Still, extremely high stiffness values, due to lowering of flexibility of asphalt layers, can lead to formation of thermal cracks. Result analysis of asphalt mixtures with partial or complete replacement of natural aggregates with recycled concrete aggregates, showed that the grain size of the RCA used had the major impact on the stiffness of tested asphalt mixtures. Several research results showed that mixtures with 100% of fine RCA (≤ 4.75 mm) replacing the natural aggregate had higher stiffness moduli thancontrol mixture [12-14].

Main objective of research presented in this paper was to estimate the possibilities of application of fine RCA in asphalt mixtures. The tests were performed on asphalt mixtures for base course,AC 22 BASE, because of the higher possible consumption of RCA and lower bitumen content in comparisonto wearing courses. In addition, due tothe lower mechanical properties of RCA, compared with natural crushed aggregate, it is more appropriate to use it in base courses, which are not directly exposed to traffic loading and environmental conditions, and therefore demand less severe technical requirements.

2. MATERIALS AND METHODS

Results of physical and mechanical tests on asphalt mixtures with different RCA content are presented in the paper. These results were compared with properties of control mixture made with natural crushed aggregate.

The maximum RCA content in the mixture was limited to 45% due to the concerns that its lower mechanical characteristics would influence the performance of the asphalt mix, and in order to avoid the need for an excessive increase in the bitumen content. One control and three asphalt mixtures with partial replacement of fine natural aggregate (0/4 mm) with RCA in amount of 15%, 30% and 45% by mass, were prepared. For example, the mark S-30 indicates a mixture in which 30% of fine natural aggregate was replaced by recycled aggregate.

In all mixtures aggregate gradation was kept the same. Targeted air voids volume was set to 5.2%. Mixtures design was determined using the Marshal method. The mixtures were then prepared and placed in different molds. Finally, water resistance, stiffness and permanent deformation resistance were determined.

2.1. COMPONENT MATERIALS

Basic physical and mechanical properties of the component materials were performed in order to design the mixtures and to determine potential influence that each of the materials used (natural aggregate, recycled aggregate, bitumen and filler), could have on the properties of asphalt mixtures. Presented research was conducted in Laboratory of pavement and Laboratory of materials at the Faculty of Civil Engineering, University of Belgrade.

Natural crushed limestone aggregate, produced by "Ravnje" – Valjevo, separated into following fractions: 0/4 mm, 4/8 mm, 8/16 mm and 16/22.4 mm was used in all the mixtures. Natural aggregate was taken from the asphalt base STRABAG in Obrenovac. The RCA used in this study was obtained by crushing cementitious concrete slabs that previously served as the sub-structure for tram rails in Belgrade, Serbia. The concrete was, during exploitation, covered with an asphalt layer, and was not directly exposed to environmental effects. At the time of removing and recycling, the concrete was more than 30 years old. The data about the quality of the concrete in question were not available. This is why three cylindrical samples (diameter 65 mm and height 65 mm) were taken out of the largerpieces of concrete for compressive strength ($f_{p,c}$) and bulk density (γ) testing. Based on the test results, presented in Table 1, it can be concluded that the class of the original concrete in the moment of placement satisfied conditions for the class C35/45.After visual examination of recycled aggregate it was concluded that the original concrete was made with three fractions of natural aggregate. In addition to RCA (98%), the used material also contained 1.2% of asphalt and 0.8% of brick debris.

Table 1. Original concrete properties

Sample	γ(g/cm^3)	f_p,c(MPa)
1	2.394	56.3
2	2.334	41.8
3	2.339	49.9

Grading curves of natural and recycled aggregate used in this study are shown in Figure 1. It can be seen that the fine fraction of RCA (0/4 mm) is finer than the same fraction of natural aggregate.

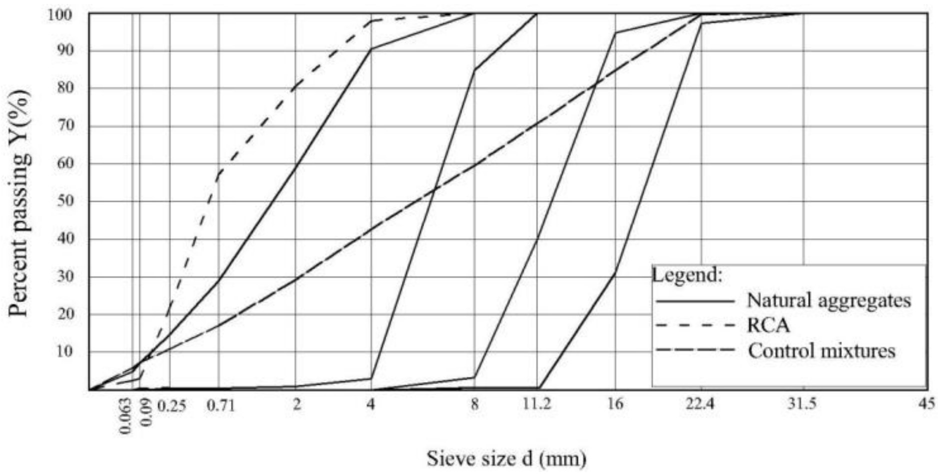

Figure1. Grading curves of natural and recycled aggregates

The main properties of the aggregates used are shown in Table 2. The RCA had a lower density compared with natural crushed aggregate, because of the residual cementitious mortar. Also, because of the higher porosity of the cementitious mortar, the RCA was characterized by higher water absorption. A decreased resistance to crushing compared with natural aggregate, expressed by a lower value of the Los Angeles (LA) coefficient, points to the inferior RCA toughness and abrasion characteristics. However, the equivalent value of LA for the mineral mixture, even with a high RCA content, was still lower than 30, satisfying the technical requirements for material classes Z3, Z4 and Z5. These materials can be applied in bituminous base and binder layers for all traffic load categories [16].

Table 2. Physical and mechanical properties of aggregate

Parameter	Units	Standard	RCA	Natural aggregate
ρ_a	(kg/m^3)	EN 1097-6	2645	2717
ρ_{ssd}	(kg/ m^3)		2512	2650
ρ_{rd}	(kg/ m^3)		2430	2580
WA	(%)		3.4	0.4

Following marks were used in table 2:

ρ_a - apparent specific gravity,

ρ_{ssd} - bulk specific gravity SSD,

ρ_{rd} - bulk specific gravity of samples dried in the oven,

WA -water absorption.

Limestonefiller produced by "Rujevac" – Ljig and asphalt binderB50/70 produced in Oil refinery in Pancevo were used in all the mixtures. The gradation of the filler is shown in Table 3.

Table 3. Filler gradation

d (mm)	0.063	0.09	0.25	0.71
Y (%)	75.9	84	97.2	100

Basic bitumen propertieswere determined through standard tests: penetration, apparent specific gravity and softening point. Results from these tests are presented in Table 4.

Table 4. Properties of asphalt binder

Test	Units	Standard	Value
Penetration	(25°C, 0.1 mm)	EN 1426	53.4
Specific gravity	(kg/m^3)	EN 15326	1004
Softening point	(°C)	EN 1427	50.5
Penetration index	(-)	EN 12591	-0.9

2.2. ASPHALT MIXTURES

Preparation of the mixtures was performed using the Marshal procedure at a temperature of 150°C, with compacting energy of two times 50 blows. Mineral mixtures were composed of: limestone filler (5%) and aggregate made of following fractions: 0/4 mm (41%), 4/8 mm (15%), 8/16 mm (24%) and 16/22.4 mm (15%). In order to provide comparison between the results gained with different mixtures, optimal bitumen content (OBC)in all mixtures was adopted for a target air voids (AV) volume of 5.2%. Table 5 presents values of OBC, AV, voids in mineral aggregate (VMA), percentage of voids filled with bitumen (VFB), density (G), maximum density (G_max), as well as Marshall stability and flow for each mixture.

Table 5 Volumetric properties of asphalt mixtures

Mix	OBC	AV	VMA	VFB	G	G_max	Stability	Flow
	(%)	(%)	(%)	(%)	(kg/m3)	(kg/m3)	(kN)	(mm)
Control (E)	3.4	5.2	13.5	61.0	2419	2553	12.0	3.3
S-15	3.5	4.9	13.4	63.2	2418	2543	12.5	3.0
S-30	3.5	4.6	13.0	64.9	2410	2525	12.8	3.4
S-45	3.6	5.4	14.0	61.1	2379	2516	12.4	3.2
Specification		5-9	NR	55–74	NR	NR	min 6	NR
* NR – not defined								

Influence of RCA on the properties of asphalt mixtures was determined on the samples prepared in a way that realistically simulates the behavior of asphalt concrete in the road structure.

2.3. SAMPLE PREPARATION

For the purposes of stiffness modulus testing, a special polygon with three 500×500×70 mm fields was prepared. After mixing, each asphalt mixture was cured for 1.5 h at a temperature of 170°C, and then laid and compacted using a roller compactor with a weight of 1000 kg. Figure 2 shows the procedure of asphalt mixture laying and compaction. In the final step, 18 beams, 50×60×400 mm in size, were cut from three slabs. Five out of these 18 beams for each mixture was used for stiffness testing.

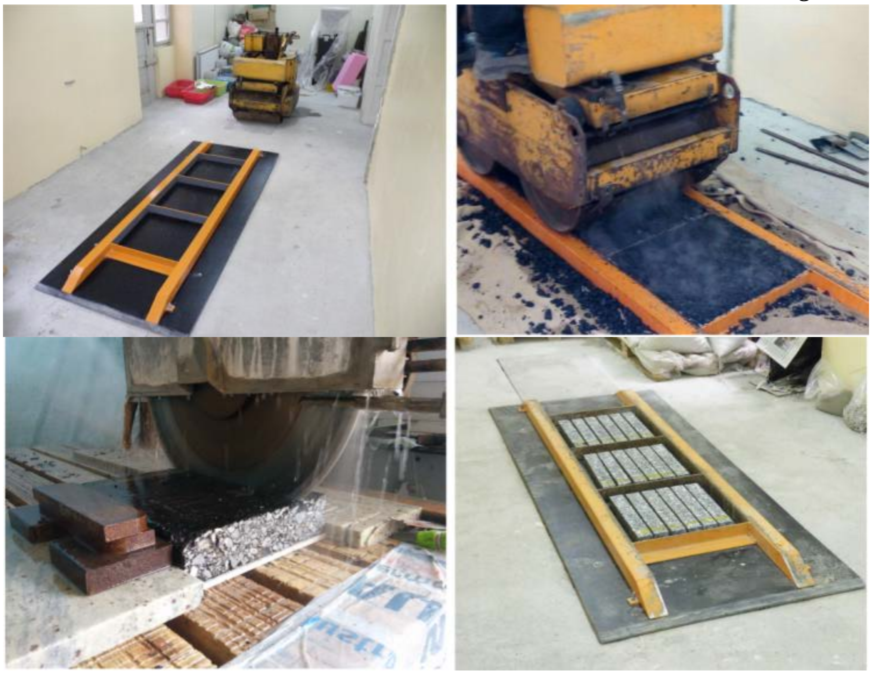

Figure 2. The procedure of beam production

During preparation of the samples used for testing of resistance to permanent deformation, in order to simulate the conditions in the asphalt plant and in situ, the asphalt mixture was conditioned before compaction at a temperature of 135°C for 4h. Two 320×260×70 mm slabs were compacted using a segment compactor, in accordance with EN 12697-33, for each asphalt mixture.

Testing of water resistance of asphalt mixtures was conducted on the Marshal samples Ø/H=101.6/63.5 mm, compacted with two times 35 blows.

3. RESULTS AND DISCUSSION

3.1. WATER RESISTANCE OF ASPHALT MIXTURES

Water resistance of asphalt mixtures was tested by measuring indirect tensile strength (ITS) of dry and wet samples, in accordance toEN 12697-12, method A. Six Marshal cylindrical samples were prepared for each of the mixtures and separated into two groups. Each group contained three samples with similar densities. The first group was kept in dry conditions,at the room temperature of 20°C.The second group was placed into water at pressure of 6.7 kPafor 30 min, and afterwards conditioned in water at temperature of 40°C during next 72 hours. Before testing, samples were held at the temperature of 25°C for 2 hours. ITS testing was conducted on the universal compression machine UTM-25 according to EN12697-23. The calculation of indirect tensile strength is shown in the following expression:

$$ITS = \frac{2 \cdot P}{\pi \cdot h \cdot d_s}$$

where:

P - maximum force(kN),

h - sample height(mm),

d_s- sample diameter (mm).

Water resistance of asphalt mixtures (ITSR) is defined as ratio between measured indirect tensile strengths of samples conditioned in wet and dry environment:

$$ITSR = \frac{ITS_{wet}}{ITS_{dry}} \cdot 100$$

Table 6 presents average values of all indirect tensile strengths of dry (ITSdry) and wet (ITSwet) samples for each of the tested mixtures, together with their ratio (ITSR).

Table 6. Average values of ITS and of ITSR

Mix	ITSdry (MPa)	ITSwet (MPa)	ITSR (%)
E	937.2	692.9	73.9
S-15	851.6	609.2	71.5
S-30	921.7	696.6	75.6
S-45	963.3	719.5	74.7

Measured values of ITS, for asphalt mixtures made with RCA, increased with higher RCA content, independently of the way of conditioning (dry or wet). These results are consequence of the better interaction and higher friction between the RCA particles, due to their rough surface and sharper edges.

Indirect tensile strength ratio (ITSR), that presents measure of water resistance of asphalt mixtures, was higher for two out of three mixtures with RCA when compared to control mixture.

3.2. RESISTANCE TO PERMANENT DEFORMATION

Testing of the resistance to permanent deformation was performed using the small wheel tracking device in air, at a temperature of 60°C, after 10000 cycles (20000 passes), all in accordance with EN 12697-22, Annex B, small appliance. Wheel load of 700 N is transferred over contact surface of 1900 mm^2 with frequency of 0.88 Hz. According to this method, resistance of asphalt mixtures to permanent deformation is determined by measuring of the depth of the track that is formed after each wheel loading cycle. Figure 3 presents the laboratory WTT (Wheel tracking test)machineproduced by INFRATEST 20-4000, that was used for this test.

Figure 3. Wheel tracking test machine

Wheel tracking test results, as a function of number of loading cycles, are presented in Figure 4.

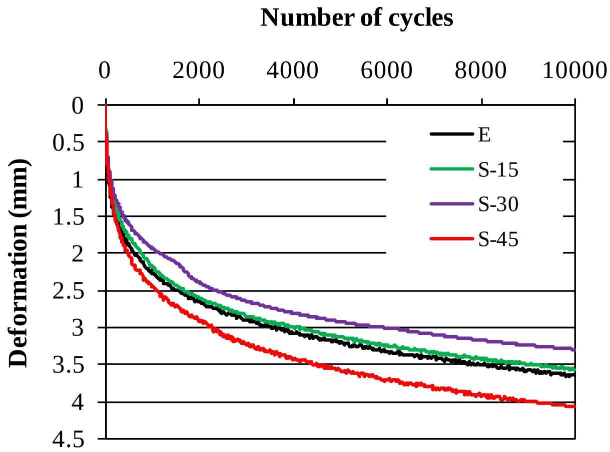

Figure 4. Permanent deformation of mixtures made with fine RCA

It can be concluded, based on the presented diagram, that partial replacement of natural with recycled aggregate did not lead to greater changes in the measured track depth. Addition of RCA in amounts lower than 30% improves the resistance of mixture to permanent deformation. This behavior can be explained by the structure and the texture of RCA. Surfaces of RCA are rough, with sharp edges as a result of being crushed multiple times, which increases the specific surface area and the friction between the aggregate particles. This provides well compaction of the grains that prevents their movement during traffic loading. Bitumen softens on higher temperatures, which causes the decrease in the bond properties and shear strength. This is why aggregate structure is the most important parameter in the resistance of asphalt mixtures to permanent deformation. Still, addition of 45% of fine RCA has led to greater permanent deformations compared to the control mixture.Nevertheless, they did not exceed 7%, the upper limit for proportional track depth according to Technical requirements for road construction in Republic of Serbia [16].Measured track depth for mixture S-45, after 10.000 cycles of traffic load was 4 mm, or 5.5% (proportional track depth).

3.3. STIFFNESS MODULUS

Stiffness modulus of asphalt concrete was tested using a four point bending beam test, in accordance with EN 12697-26, Annex B. The test was carried out at temperatures of 5°C, 15°C and 25°C, at frequency of 8 Hz. The dynamic load took the form of a sinusoidal function ("haversine") with controlled strain of 50 με, to avoid the possibility of fatigue damage. Differently to ordinary sinusoidal function, "haversine" sinusoid creates only tension induced strain on one side, and only compression induced strain on the other side of the sample. In this way, strain control is performed with no transition of the beam through neutral position thatwould lead to probable relaxation of the material. Test duration was limited to 100 cycles, to prevent the occurrence of the permanent deformations and change in the stress state in beams. Disposition of the stiffness modulus test is shown in Figure 5.

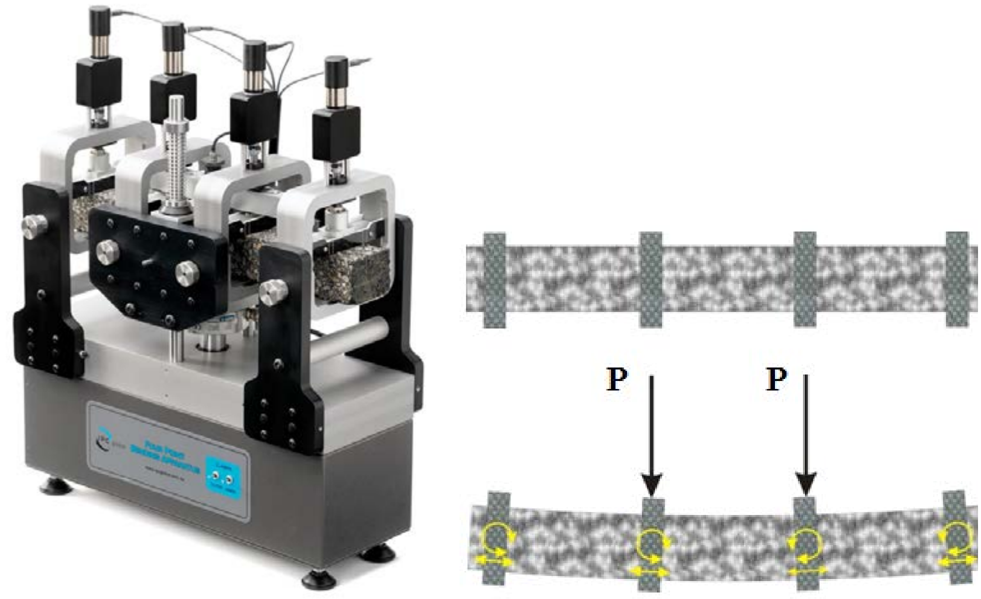

Figure 5. Disposition of the stiffness modulus test

Figure 6 presents average values of stiffness modulus (absolute values of the complex modulus |E*|) at frequency of 8 Hz after 100 load cycles, in accordance with EN 13108-20:2006 (Annex D).

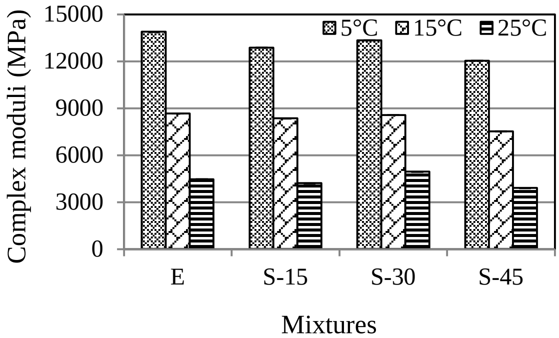

Figure 6. Stiffness modulus at all three testing temperatures at a frequency of 8 Hz

The average stiffness moduli of all mixtures with RCA were lower than the modulus of the control mixture. Still, the strong dependence between the amount of the RCA used and the stiffness moduli values could not be determined. This is consequence of the complex behavior of the asphalt mixtures with RCA. Due to the lower mechanical properties of RCA compared to natural aggregate, it was expected that the stiffness decreases with the increase of the amount of RCA in the mixture. However, because of the rough surface and sharp edges of the RCA interaction and friction between grainsare increased, sothat the load induced movements of the grains are prevented. RCA is more porous and has greater specific surface area when compared to natural aggregate grain, which impliesthinner layer of bitumen around aggregate particles [17].

4. CONCLUSION

In order to support implementation and promotion of sustainable development in civil engineering, wide range of tests were conducted on RCA and asphalt mixtures with RCA. The main objective of the research presented was to evaluate the possible application of RCA in asphalt mixtures, in accordance with the official technical requirements. Tests were performed on asphalt mixtures for base course, AC 22 BASE. The following conclusions can be made, based on the presented results:

- When compared to the natural crushed (stone) aggregate, RCA has lower density, due to remaining cement mortar and higher water absorption related to the higher porosity of cement mortar.
- Differences between water resistance of mixtures with RCA and control mixture were between-2.4% and +1.7%. that is negligible from the point of the potential application in asphalt mixtures. As Technical requirements for road construction in the Republic of Serbia [16] do not prescribe minimal conditions for water resistance of asphalt mixtures, it can be concluded that from this aspect there are no obstacles for partial replacement of natural aggregate with RCA in amount of 45%.
- Partial replacement of natural aggregate with RCA in amount of 45%, does not substantially affect the tracks depth during the permanent defomation resistance determination. Addition of up to 30% of RCA increases the mixture resistance to permanent deformation. Highest measured proportional track depth was 5.5% which is lower than 7% (allowed limit according to Technical requirements for road construction in the Republic of Serbia) [16].
- Although, asphalt concrete mixtures with recycled aggregate had lower stiffness modulus than control mixture,these differences were not substantial. Similarly as in case of water resistance, Technical requirements [16] do not define minimal values for stiffness modulus. It can be concluded that it is possible to use fine recycled aggregate in asphalt mixtures in amounts up to 45%.

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