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WASTE RUBBER - SUSTAINABLE PAVEMENTS SOLUTION?

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Abstract

Cement bound base courses increase pavement bearing capacity and resistance to detrimental effects of frost along with being a good base for surface courses. Due to its stiffness, cement bound base courses reduce vertical deflections and tensile stress in asphalt layers thus reducing fatigue and appearance of alligator cracks in asphalt. But, in order to generate required layer strength and stiffness of cement bound base, appropriate amount of cement is necessary. This in turn can cause shrinkage induced cracks which spread towards surface courses and cause accelerated deterioration of pavements. To prevent rapid deterioration of pavement surface layers and occurrence of reflective cracking, incorporation of recycled rubber from waste tire in mixtures for cement bound base courses is currently being considered. In this paper a short review of waste tire application and its behaviour in pavement structures will be shown. In addition, planned methodology and activities that are going to be conducted with in a research project are going to be discussed.

Keywords: sustainable pavements, base course, waste tire

1 Introduction

The Transport Development Strategy of the Republic of Croatia 2017-2030 [1] states that the main road network in the Republic of Croatia has been established, and it mainly consists of highways. Given the economic situation and the high quality of these roads, most of the developed countries, including the Republic of Croatia, are reducing investment in the construction of highways and turning their investments into the construction, reconstruction and modernization of lower category roads and maintenance of the existing network to extend their life span. Thus, according to the Public Roads Construction and Maintenance Program for the period 2017-2020 [2] 55 % of all funds, were planned to be invested in state roads network and it is expected that trend to be continued within the next planning period. At the same time, the Strategy [1] among other things cites the need to reduce the impact of transportation system on climate change and the environment, as the basic goal of further transportation system development.
State roads pavement, due to the traffic load, is built with a cement-stabilized bearing course (CBC). CBC are installed in a pavement structure to increase its bearing capacity, they are good base for surface courses and they increase the pavement resistance to the detrimental effect of frost. The installation of these layers results in reduced fatigue in asphalt layers and appearance of alligator cracks as their stiffness reduces vertical deflection and deformations of asphalt layers caused by tensile stress. On the other hand, using cement in base and subbase courses increase their stiffness leading to appearance of cracks. Cracks occur due to the shrinkage of material and are reflected on the surface of asphalt layers. So, here lies

the potential for exploring new materials and techniques for installation in CBC with the goal of reducing roadway maintenance, extending its life span, reducing reflective cracks occurrence and being environmentally friendly.
With the aim to prevent deterioration of pavement surface and reduce usage of natural materials, other materials have been researched to implement in pavement construction. Material with great potential is waste rubber and its potential usage in CBC is the objective of a new scientific project funded by Croatian Science Foundation which will be presented within this paper.

2 Waste rubber application in road construction

2.1 Waste rubber in asphalt mixtures

Crumb rubber is added to the asphalt mixtures as an additive in order to improve some of the mixture properties, such as the resistance to rutting, reduction of the fatigue cracking and low-temperature cracking or the reduction of the noise emission [3]. According to the many researches performed in order to investigate the effect of the crumb rubber in the asphalt mixtures, the general conclusion is that the addition of the crumb rubber extends the life span of the flexible pavement construction. In comparison to standard industrial additives such as SBS, SBR or EVA polymers, it is more ecological and less costly [4].
The rubber asphalt is produced by wet or dry process. In the wet process, the rubber waste from vehicle tires is a part of the asphalt binder, either dissolved in the liquid asphalt binder before mixing (as a part of the binder) or by substituting a portion of fine aggregate with ground rubber which does not completely react with the binder. In the dry process, the crumb rubber is substituting a percentage of aggregate particles in the asphalt mixture and it is not a part of the binder [4].
When the crumb rubber is added as a part of the binder in the wet process, it influences the rheological properties of the mixture such as viscosity, softening point, penetration, temperature susceptibility, strength and durability [5]. Viscosity and the temperature susceptibility tend to increase with the crumb rubber addition. Also, the homogeneity of the mixture is disrupted which causes the reduction in the penetration and the ductility and consequently makes the mixture stiffer [6]. The strain capacity of the mixture is also increased, which means that the rubber-modified mixture is more flexible and tough [5]. The Marshall stability is higher for low percentage of crumb rubber [6], but when the amount of crumb rubber is higher than 10 % from the bitumen weight the Marshal stability decreases which means that the strength and the quality of the mixture is reduced. The investigation of dry process-produced crumb rubber asphalt mixture properties show that the addition of the rubber could improve the resistance to permanent deformation and low-temperature cracking [7]. Due to the less amount of the binder content needed in the crumb rubber mixture, the amount of air voids in the mixture and the permeability increases, which can cause a reduction of the mixture durability [6]. The performed investigations of asphalt mixture properties modified with the crumb rubber lead to the conclusion that the amount of the rubber and the production process of the modified asphalt mixture significantly influences the final properties.

2.2 Waste rubber in subgrade, subase and base layers

Available literature also provides numerous researches on the applicability of waste crumb rubber in lower layers of road construction and in stabilization of local soil / subgrades. Research into application of rubber on its own or in combination with binders, such as cement, for clayey soil stabilization show different results, which largely depends on the amount and type (shape and size) of the used rubber. Yadav and Tiwari [8] state that the presence of the rubber can lead to reduced strength due to weaker bonds and less friction between crumb rubber and clay particles or due to lower stiffness in cement-stabilized mixtures. However, in their research, there was a slight increase in compressive strength and increase of California Bearing Ratio (CBR) by addition of 2.5 % rubber to clay soil, while further increase in tire volume resulted in a decrease of measured values. In the same study, in cement stabilization, the rubber reduced compressive and indirect tensile strength, but resulted in ductile behaviour of these mixtures.

Li et al. [9] investigated the applicability of crushed rubber in unbound layers from recycled aggregate and crushed stone. Measurement of CBR showed that small tire fractions act as filler, and CBR increased with increased content of fine rubber fraction from 0.5 % to 2 %. For coarser rubber particles, the optimal proportion is 1 %, followed by a significant drop in CBR. In addition, the crumb rubber increases failure strain in relation to the control samples. Arulrajah et al. [10] also found a reduction in the stiffness upon addition of crumb rubber to the mixture of waste crushed rock. Research has shown that the optimum replacement ratio of aggregate with crumb rubber is 2 % by which the engineering properties are equivalent to those of a natural aggregate. The CBR of all the blends has met the conditions set for application in base/subbase layers, whereas application in the base layers is not possible only when the 3 % coarse fraction of crumb rubber is applied.

2.3 Waste rubber in concrete pavement

The addition of Portland cement to unbound grained material improves its mechanical properties, but it certainly increases stiffness, and this layer becomes more susceptible to cracking and fatigue failure [11]. Considering the dynamic nature of traffic loads, research has also been carried out over the last couple of years to explore the application of rubber in a conventional or roller compacted concrete for pavements. The application of rubber in concrete presents the addition of elastic material to a rigid concrete matrix that changes its properties [12]. Numerous studies of the use of crumb rubber in concrete suggest that the addition of rubber and increase of its amounts in concrete usually has a negative effect on mechanical properties such as compressive, indirect tensile and flexural strength, modulus of elasticity and density [13,9,14]. Strength reduction is described as a result of poor bonds between cement paste and rubber particles and also because rubber with low modulus of elasticity that is imbedded in concrete of high strengths, acts like a void [13,12]. But the rubber addition also increases the capacity of concrete for energy absorption and ductility and reduces the possibility of brittle fracture. The addition of rubber to concrete increases the number of load cycles that will lead to fracture or fatigue of the material [15]. Kardos and Durham [16] investigated the possibility of applying fine aggregates of crushed rubber as a volumetric sand replacement (10, 20, 30, 40 and 50 %) in concrete pavements. The results of this research have shown that the replacement of sand with crumb rubber shows satisfactory properties of fresh and hardened concrete with a rubber share of up to 30 %. With the addition and increase in rubber share, the drop in compressive and indirect tensile strength was noted, but the samples were ductile, could take higher deformations, and had residual load capacity after failure.

Pacheco-Torres et al. [12] have established a methodology for measuring the deformations in concrete mixtures with crumb rubber, created to evaluate mixtures for pavements under cyclic loads. They found that 20 % of the rubber aggregate significantly reduces the mechanical properties but that up to 10 % of the rubber of different granulations achieves better deformability and performance of the material under cyclic load with an acceptable reduction in mechanical properties. Similar conclusions are presented also in [17].

3 Project RubSuPave

Despite the widely researched application in concrete and asphalt, crumb rubber as an alternative material for construction of cement stabilized layers is sparsely researched in available literature. In the greatest extent, Farhan and his associates [11, 18, 19] dealt with the application of crumb rubber in cement stabilized layers. Although researches in the area of waste rubber application in cement stabilized base layers of pavement structures are limited, there are indications that its application could result in a reduction of shrinkage cracking. However, the optimum mix composition (optimal amount of cement, optimum tire aggregate content), and in particular the effect on behaviour of asphalt courses in this kind of pavement structure, is not yet fully explored. This is where innovation is seen in the field of application of automotive waste tires for pavement structures.

Research project called Cement stabilized base courses with waste rubber for sustainable pavements is based on aspiration to examine application of waste rubber in cement stabilized base course (CBC). The project gathers scientists from different fields of civil engineering from the Faculty of Civil Engineering in Rijeka, GIC Gradnje d.o.o. Rogaška Slatina, Slovenia and from the Faculty of Civil Engineering and Architecture Osijek as a project leader. The possibilities for improving behaviour of pavement incorporating CBC will be researched through an analysis of the possibility of recycled rubber replacement for fine aggregate fractions. Firstly, extensive laboratory research will be conducted within which material mechanical properties will be defined and upon that, optimal mix composition. For the purpose of defining the optimal CBC mix of satisfactory strengths and improved elastic properties, the first subgroup of laboratory research will be conducted. Within mix composition, binder ratio and waste rubber granulation (Fig.1.) will be varied.

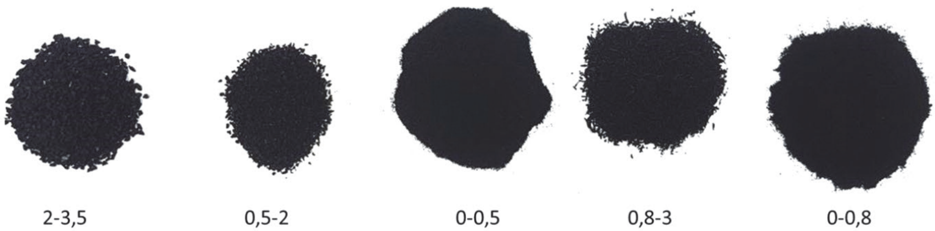

Figure 1 Different waste rubber granulation (mm)

After defining material mechanical properties, statistically analyses of the results and comparison to the valid technical requirements will be done and the mixtures will be ranked according to the required properties. After the material characterization of CBC with waste rubber at one level, behaviour and impact of this layer on the asphalt wearing course will be examined. Samples of asphalt wearing course (two different types) will be installed on the CBC samples and the behaviour of the CBC – wearing course system will be monitored by 3D-DIC method under cyclic loading as traffic load simulation. During the test, pavement course deflections and crack development will be measured in order to develop pavement behavioural model. Based on the laboratory research results, pavement spatial numerical models will be developed using the finite element method. Results gained by laboratory tests, as well as those gained by the numerical modelling, will be used as input parameters for the optimization model which will provide optimal or near optimal design of cement-stabilized bearing layer with the addition of recycled tires.

Numerical and optimization models verification and validation will be performed through constructing and testing a test section with the defined optimal mix of CBC. The test section will be built with CBC without waste rubber (reference section) and with CBC containing waste rubber, in equal dimensions. Within the last year of project, pavement condition will be monitored by means of measuring cracks and deformations development. Weather conditions will be also monitored (air temperature, pavement warming and rainfall) as well as traffic loads. Summary of research activities is shown on Fig. 2.

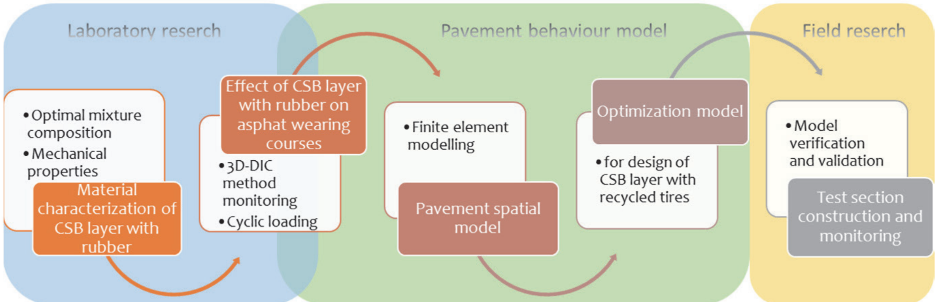

Figure 2 Diagram of project activities

The importance of exploring the proposed subject is emphasized in two aspects: the reduction of the application of natural materials to which road construction traditionally relies on and the extension of pavement life time. The use of waste rubber in CBC has the potential to reduce cracks occurrence in this layer, which results in reflective cracking on asphalt layers. This will reduce the need for road maintenance and extend its lifespan, which will result in savings of financial resources and reduced energy consumption.

4 Conclusion

Waste rubber, as is shown in various literature, can be a beneficial material for construction of different pavement layers, from wearing courses to subgrade. Its application can especially be beneficial for elastic properties and deformability, reduction of fatigue cracking and performance of material under cyclic loading. Despite this benefits, application in cement bound courses, the most rigid layer of flexible asphalt pavements, has been sparsely investigated and just on material level. This CBC layer can highly effect properties of wearing courses by causing shrinkage induced cracks which spread towards surface and thus accelerating deterioration of pavements. Therefore, in a research project Cement stabilized base courses with waste rubber for sustainable pavements, along with material properties of CBC with waste rubber, its effect on asphalt courses and overall pavement should be determined. To better understand the effect waste rubber in CBC has on pavement laboratory reaserch, field research, pavement modelling and model optimization are planned.
Results of this scientific project will contribute to the creation of new knowledge on the practical application of waste tires in cement stabilized base layers. Also, the project activities are aimed at solving and improving the practical goal: creating a sustainable roadway through the application of waste material and extending the life of the road construction.

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References

[1] Ministarstvo mora, prometa i infrastructure: Strategija prometnog razvitka Republike Hrvatske 2017-2030, 2017, https://vlada.gov.hr/UserDocsImages/ZPPI/Strategije/MMPI%202017-2030%20STRAT%20PROM%20RZV%20RH%2025-8_17.pdf, 3.4.2019

[2] Vlada Republike Hrvatske: Program građenja i održavanja javnih cesta za razdoblje 2017-2020, 2017, NN 47/2017

[3] Issa, Y.: Effect of Adding Waste Tires Rubber to Asphalt Mix, International Journal of Scientific Research and Innovative Technology, 3 (2016) 5, pp. 61-68

[4] Mashaan, N., Ali, A., Karim, M., Abdelaziz, M.: A review on using crumb rubber in reinforcement of asphalt pavement, The Scientific World Journal, 2014, doi: http://dx.doi.org/10.1155/2014/214612

[5] Tuncan, M., Tuncan, A., Cetin, A.: The use of waste materials in asphalt concrete mixtures, Waste Management&Research, 21 (2003), pp. 83–92, doi: https://doi.org/10.1177/0734242X0302100202

[6] Wulandari, P., Tjandra, D.: Use of Crumb Rubber as an Additive in Asphalt Concrete Mixture, Procedia Engineering, 171 (2017), pp. 1384-1389, doi: https://doi.org/10.1016/j.proeng.2017.01.451

[7] Cao, W.: Study on properties of recycled tire rubber modified asphalt mixtures using dry process, Construction and Building Materials, 21 (2007) 5, pp. 1011-1015, doi: https://doi.org/10.1016/j.conbuildmat.2006.02.004

[8] Yadav, J. S., Tiwari, S. K.: Effect of waste rubber fibres on the geotechnical properties of clay stabilized with cement, Applied Clay Science, 149 (2017), pp. 97–110, doi: https://doi.org/10.1016/j.clay.2017.07.037

[9] Li, J., Saberian, M., Nguyen, B.T.: Effect of crumb rubber on mechanical properties of crushed recycled pavement materials, Environmental Science and Engineering, 218 (2019), pp. 291–299, doi: https://doi.org/10.1016/j.jenvman.2018.04.062

[10] Arulrajah, A., Mohammadinia, A., Maghool, F., Horpibulsuk, S.: Tyre derived aggregates and waste rock blends: Resilient moduli characteristics, Construction and Building Materials, 201 (2019), pp. 207–217, doi: https://doi.org/10.1016/j.conbuildmat.2018.12.189

[11] Farhan, A.H., Dawson, A.R., Thom, N.H.: Characterization of rubberized cement bound aggregate mixtures using indirect tensile testing and fractal analysis, Construction and Building Materials, 105 (2016), pp. 94–102, doi: http://dx.doi.org/10.1016/j.conbuildmat.2015.12.018

[12] Pacheco-Torres, R., Cerro-Prada, E., Escolano, E., Varela, E.: Fatigue performance of waste rubber concrete for rigid road pavements, Construction and Building Materials, 176 (2018), pp. 539–548, doi: https://doi.org/10.1016/j.conbuildmat.2018.05.030

[13] Shu, X., Huang, B.: Recycling of waste tire rubber in asphalt and portland cement concrete: An overview, Construction and Building Materials, 64 (2014) B, pp. 217-224, doi: https://doi.org/10.1016/j.conbuildmat.2013.11.02

[14] Sofi, A.: Effect of waste tyre rubber on mechanical and durability properties of concrete – A review, Ain Shams Engineering Journal, 9 (2018) 4, pp. 2691–2700, doi: https://doi.org/10.1016/j.asej.2017.08.007

[15] Zhang, Y.M., Zhao, Z.: Internal Stress Development and Fatigue Performance of Normal and Crumb Rubber Concrete, Journal of Materials in Civil Engineering, 27 (2014) 2, pp. 1-9, doi: https://doi.org/10.1061/(ASCE)MT.1943-5533.0001000

[16] Kardos, A.J., Durham, S.A.: Strength, durability, and environmental properties of concrete utilizing recycled tire particles for pavement applications, Construction and Building Materials, 98 (2015), pp. 832–845, doi: https://doi.org/10.1016/j.conbuildmat.2015.08.065

[17] Strukar, K., Kalman Šipoš, T., Dokšanović, T., Rodrigues, H.: Experimental Study of Rubberized Concrete Stress-Strain Behavior for Improving Constitutive Models, Materials, 11 (2018), 2245, doi: https://doi.org/10.3390/ma11112245

[18] Farhan, A.H. et.al.: Flexural characteristics of rubberized cement-stabilized crushed aggregate for pavement structure, Materials and Design, 88 (2015), pp. 897–905, doi: https://doi.org/10.1016/j.matdes.2015.09.071

[19] Farhan, A.H., Dawson, A.R., Thom, N.H.: Effect of cementation level on performance of rubberized cement-stabilized aggregate mixtures, Materials and Design, 97 (2016), pp. 98–107, doi: https://doi.org/10.1016/j.matdes.2016.02.059