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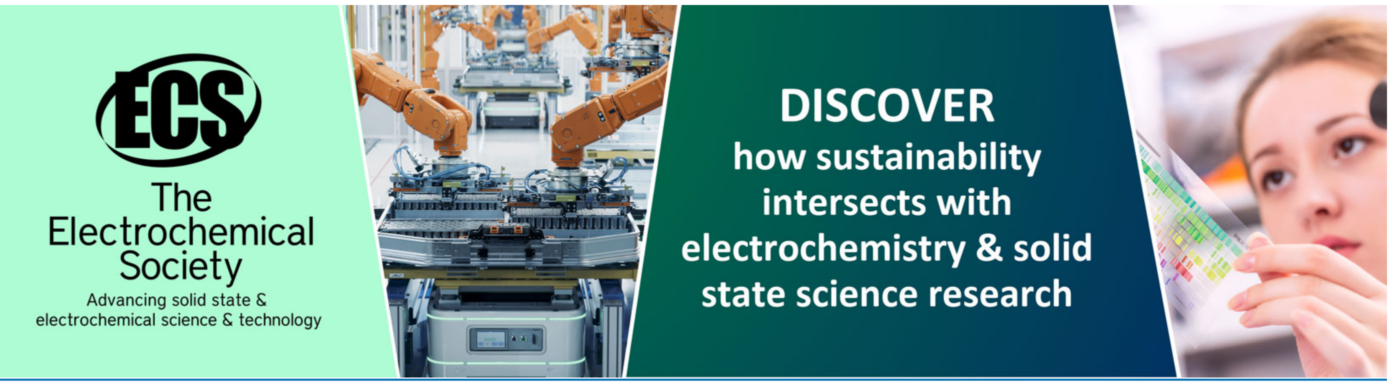

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PRELIMINARY RESEARCH ON WASTE RUBBER APPLICATION IN CEMENT BOUND BASE LAYER

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Abstract. Besides all the positive characteristics of cement bound courses (CBC), it has some detrimental effects on the pavement wearing courses. Due to cement hydration, this mixture is affected by shrinkage. Shrinkage induces cracks in the whole layer which along with weather conditions propagate through asphalt layers in a short period. Also, it's stiffness negatively affects cracks propagation without providing elastic support for upper layers. As a result, roads are covered with various damages which reduces driving comfort and safety and demand new financial investments. The focus is on reducing the detrimental effect of CBC on the pavement. Nowadays, large quantities of recycled rubber can be found on the market. Wasted rubber is a large ecological problem due to its long decomposition period. On the other hand, by mechanical grinding and separation process, suitable fractions of rubber can be obtained for use in construction. Consequently, the replacement of conventional material by crumb rubber reduces the consumption of natural material and energy for its exploitation. Appropriate amounts and fractions of recycled rubber have the potential to reduce shrinkage and increase the elasticity of CBC. Within this paper, preliminary research results will be presented on the possibilities of crumb rubber implementation in CBC and its effects on mechanical characteristics. By using recycled materials in construction processes we undertake a major step in the sustainable management of natural resources.

Keywords: cement bound base layer, pavement, rubber, compressive strength, ultrasound pulse velocity.

1. Introduction

Nowadays, when we are witnesses to the rapid development of technology and science, the emphasis is on the pronounced mobility of people, goods and services. That entails a need for fast development of transportation infrastructure in terms of railways, air transport, sea traffic and, the most, road infrastructure. Under the TEN – T project, European Union plans to build nine network corridors that connect the most important nodes of the European Union until 2030 (Trans-European Transport Network (TEN-T) n.d.). Enormous quantities of natural raw materials are needed for such an infrastructure project which conflicts with our efforts to establish greater sustainability and nature preservation. Construction of such infrastructure is a great opportunity to investigate and implement some new, sustainable, technics and materials in road infrastructure. While on one hand, large amounts of natural raw materials are needed, on the other hand, large amounts of long-time decomposing waste are disposed of in nature. End of life road vehicles tires is such a kind of waste. According to (Mashiri et al. 2015) about 1.5 million scrap tires reach their end of life every year. Considering the population growth and monetary status increase, this number also rises through recent years. Waste tires in their original shape are useless for construction, so they go through a six-step process where cutting, separation of metal and textile particles and final grinding to desired granulation is carried out (Dobrota, Dobrota, and Dobrescu 2020). Shredded and crumb rubber of different granulations can be found on the market. In the construction industry, recycled rubber has its part in several areas. Crumb rubber can be added to asphalt mixtures where it takes a dual role depending on the type of production process. There are three possible production processes for rubber modified asphalt: dry, wet and terminal blend. In the dry process, crumb rubber is added to the asphalt mixture before the asphalt binder, which represents a partial substitute for fine coarse aggregate. Contrary, finer rubber particles are added into hot liquid asphalt before mixing with aggregate in the wet process. While in the dry process, crumb rubber plays its role as an aggregate, in the wet process rubber particles melts under high temperatures and unites with a binder. The terminal blend process can be interpreted as a type of wet process where the crumb rubber is blended with the asphalt binder at the asphalt terminal (Bakheit and Xiaoming 2019; X. S. B. Huang n.d.). Ding et al. (2019) claim that asphalt mixture composed of recycled asphalt and stable crumb rubber made by wet process improves asphalt's high temperature and low-temperature performance,

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moisture stability and fatigue resistance comparing to virgin asphalt mixture. Also, this research states that a stable crumb rubber can increase the proportion of recycled asphalt in the asphalt mixture. Da Silva et al. (2018) investigated the influence of crumb rubber on the propagation of reflective cracks and fatigue life of dry mix asphalt mixtures. Their experiment shows that crumb rubber in the asphalt mixtures increases resistance to reflection cracking and fatigue resistance. Also, in their previous study (da Silva, Benta, and Picado-Santos 2018) they concluded that crumb rubber asphalt produced by both, dry and wet process, develop the same performance in terms of fatigue life and rutting resistance. Chen et al. (2020) state that asphalt mixtures with ground tire rubber can increase rutting resistance. From those researches, the advantage of using recycled rubber in asphalt mixture is obvious. Contrary, Yang et. al (2018) have focused their research on the harmful impact of the use of crumb rubber in hot mix asphalt mixtures and found out that its use largely contributes to hazardous emissions such as xylene and toluene. Furthermore, recycled rubber can be used as a replacement for aggregate in cement bound base course (CBC). Some papers which investigate the use of rubber in CBC have been published. In their extensive researches, Farhan et al. (2020) investigated the possible use of recycled rubber and steel fibres from old tires in subbase layers and concluded that implementation of recycled rubber in cement bound aggregates affect the density of mixture due to low specific gravity of rubber and damping action of rubber on compaction. Furthermore, those papers revealed that recycled rubber has a positive effect on the appearance and propagation of cracks. Namely, by examining the internal structure of failed specimens, they noticed that cracks propagated through rubber particles, which implies that rubber particles absorb energy. By conducting an Ultrasonic Pulse Velocity (UPV) test, researchers measured lower values than for virgin mixtures, which are characteristic of less stiff materials. In papers (Jie Li, Mohammad Saberian 2018; Saberian et al. 2018, 2020; Saberian, Li, and Setunga 2019), recycled concrete aggregate and crushed rock mixed with coarse and fine rubber and, in some mixtures, with crushed glass were prepared and tested in a triaxial testing machine. It was concluded that recycled aggregates with a small amount of rubber could be used in subbase and base pavement layers. Considering that recycled concrete has inferior characteristics compared to natural materials, it is likely that higher amounts of crumb rubber could be used in mixtures with natural raw materials. In their paper, Wei et al. (2015) examined the effect of freeze-thaw cycles on silty clay modified with fly ash and crumb rubber under dynamic loading. The conclusion of their research claims that rubber and ash modified mixtures are superior to unmodified ones. Nevertheless, crumb rubber can be used in some other construction projects. Firstly, and the most noticeable application of RC is at playgrounds and sporting surfaces where this surface type provides better protection against serious injuries (T. J. Huang and Chang 2009). Waste rubber also finds its application in railway construction. In their research, Asgharzadeh et al. (2018) concluded that rubberized asphalt mixtures show better performance under cyclic traffic load than virgin asphalt mixtures and they would provide better support for railways in the track – bed structure.

Given all possible applications and previous researches, this study aims to examine the influence of various amounts of crumb rubber on the mechanical properties of cement bound base course (CBC) mixtures for heavy traffic load pavement application. Here are presented preliminary results of ongoing research to define optimal rubber and binder content in CBC to produce a crack-resistant material for asphalt pavement reflective cracking reduction.

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2. Materials and methods

2.1. *Materials*

For the preparation of CBC test specimens, sand and three different fractions of gravel from the Sava river were used, 0-4 mm, 4-8 mm and 8-16 mm. In accordance with European norm (European committee for standardization 2013a), solid particle densities of natural aggregate were determined in a pycnometer. The density of sand is 2,86 g/cm^3, while densities of 0-4 mm, 4-8 mm and 8-16 mm gravel fractions are 2,96, 2,63 and 2,70 g/cm^3 respectively. Besides the aggregates for virgin CBC mixtures, crumb rubber of nominal grain size 0-0,5 mm was used for rubber-modified mixtures. In accordance with the above-mentioned norm, the density of used rubber was determined in ethanol instead of water due to its low density. The density of crumb rubber is 1,12 cm^3. As a binder, Portland cement of grade 32,5 (CEM II B/M (P-S) 32,5R) was used comprising 5% of aggregate mass for the reference mixture (C5R0). The density of used cement is 2,92 g/cm^3, determined in a pycnometer using petroleum, according to (European committee for standardization 2018). Virgin mixtures consist of the same mass amount of all four fractions (25% of sand and each gravel fractions), cement and optimum moisture content determined using the Proctor compaction method in accordance with standard EN 13286-2 (European commitee for standardization 2010). The gradation curve of the used aggregate is presented in Figure 1 and it can be classified as a cement bound granular mixture 4 (CBGM 4), according to EN 14227-1(European commitee for standardization 2013b). Cement content was determined according to previous research results based on 28-day compressive test results (Barišić 2012). Due to their similar gradation curve, sand was replaced by rubber, while the gravel fractions kept their mass ratio in mixtures. Considering that sand has a 260.71% higher density than rubber, the rubber replaced sand by volume. Three different rubber modified mixtures were designed, replacing 20, 30 and 60 vol.% of sand (C5R20, C5R30 and C5R60 respectively) with rubber.

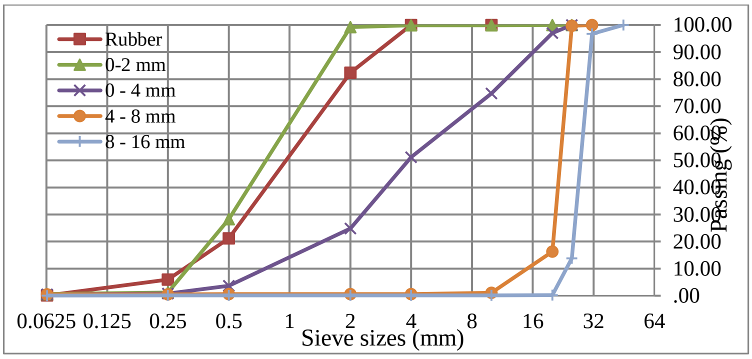

Figure 1. Grain size distribution of used aggregate

2.2. *Specimen preparation and testing*

The maximum dry density (MDD) and optimum water content (OWC) for every mixture were determined following (European committee for standardization 2010). Three of a kind specimens were prepared using the modified Proctor compaction method according to recommendations of (European committee for standardization 2004) (Figure 2.). Three samples were made for each mixture to eliminate possible deviations of laboratory results. After compaction, specimens were demoulded and wrapped into cling film to prevent loss of moisture during the curing period. Wrapped specimens were cured in a climate chamber for 28 days at a temperature of 20°C and humidity of 90%. After the curing period, specimens were unwrapped, measured and weighed. Ultrasonic pulse velocity (UPV) was measured according to (CEN/TC104 2004), to calculate the dynamic modulus of elasticity (Figure 3). This test is usually performed for concrete samples, but some researches prove that UPV measurement gives results of great significance for CBC mixtures as well (Barišić, Dimter, and Rukavina 2016; Dimter, Rukavina, and Barišić 2011). From the obtained time and height of the specimen, ultrasonic pulse velocity can be calculated according to the following equation:

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$$UPV = \frac{L}{T}$$

Where:
UPV – the pulse velocity [km/s]
L – the path length [mm]
T – the time taken by the pulse to transverse the length [μm].


Figure 2. Compacted and demoulded specimen


Figure 3. UPV measurement

Based on ultrasonic pulse velocity, the density of the specimens and Poisson's ratio, the dynamic modulus of elasticity can be calculated. Poisson's ratio is adopted as ν = 0,25. The equation for the dynamic modulus of elasticity calculation is the following:

$$E = \rho \times v^2 \frac{(1 + \nu)(1 - 2\nu)}{1 - \nu}$$

Where:
E – the dynamic modulus of elasticity [MN/m2]
ρ – the density of the specimen [kg/m3]
v – the pulse velocity [km/s]
ν – the Poisson's ratio

After non-destructive measurements, specimens were tested in a universal testing machine to determine their 28-day compressive strength. Testing of compressive strength was conducted in compliance with (European committee for standardization 2003). The load was applied uniformly and the maximum stress of the specimens occurred between the 30th and 60th second of commencement of loading. The compressive strength is defined as the stress at maximum load on a specimen when tested in uniaxial unconfined compression. It is calculated as a ratio of the force to the surface on which the force acts - a round surface with a diameter of 100 mm. The form of an equation is:

$$f_{c,28} = \frac{F}{Ac}$$

Where:
fc,28 – the compressive strength of the specimen of hydraulically bound mixtures [N/m2]
F – maximum force sustained by the specimen of hydraulically bound mixtures [N]
Ac – cross-section area of the specimen of hydraulically bound mixtures [mm2].

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Figure 4. presents specimen failure under compression strength test with a satisfactory failure pattern according to (European commitee for standardization 2003a).

Figure 4. Broken specimen after compression

3. Results and discussion

Results of conducted tests are presented in Table 1.

Table 1. Dynamic modulus of elasticity and compressive strength results

Mixture/parameter	MDD [g/cm3]	OWC [%]	UPV [km/s]	E [GPa]	fc28[MPa]
C5R0 (reference mix)	2,12	5,87	4,06	31,49	7,60
C5R20	2,06	5,53	2,98	16,57	3,41
C5R30	2,03	5,13	2,40	10,50	2,48
C5R60	1,89	4,94	0,37	0,45	0,94

Addition of rubber results in a drop of all tested mechanical properties. As expected, there is a drop in MDD and OWC with the increase in rubber content due to the hydrophobic nature and lower density of rubber compared to sand. These results are in accordance with (Farhan et al. 2015; Sun et al. 2020).

MDD drop for 20, 30 and 60 vol. % sand replacement by rubber is 2,83%; 4,25% and 10,85% respectively compared to the reference mix. However, E drop is 47,30%; 66,67% and 98,41% respectively comparing to reference mix. This high drop in E value means that replacing sand with rubber results in a less stiff material which could be beneficial for crack occurrence delay within the layer. Also, this high difference between MDD and E drop with rubber addition cannot be only due to the difference in material densities, but to a change in materials behaviour. The same goes for UPV results, dropping by 26,60%; 40,88% and 90,89% respectively. This is going to be investigated within the next research phase.

A piece of important information for the evaluation of cement bound mixture for use in the pavement is the 28-day compressive strength. According to (General technical conditions for road works 2001), the required value of a mentioned parameter for heavy traffic load is within the range of 2,5 MN/m^2 to 6 MN/m^2. From Table 1. it can be seen that all tested mixtures except C5R60 achieve the required minimum value. Rubber addition resulted in a compressive strength decrease which was predicted based on previous researches (Farhan, Dawson, and Thom 2016b). According to Table 1. a great dropdown trend can be observed by an increase of rubber content in the mixture. The drop in compressive strength of C5R20, C5R30 and C5R60 is 59,21%; 67,11% and 88,16% respectively compared to the reference mix. It can be observed that the decreasing nature of compressive strength is consistent with the drop in the dynamic modulus of elasticity. Despite the decrease in compressive strength, obtained results show that the mixture with 20% of rubber satisfies the condition for use in heavy traffic load pavement, while the mixture with 30% of rubber achieved the minimum required value. For higher cement content, higher rubber content could be used if compressive strength criteria should be the most important one. The influence of rubber replacement level depending on different cement content in a view of compressive strength, elastic behaviour and crack occurrence reduction is to be investigated within the next research phase.

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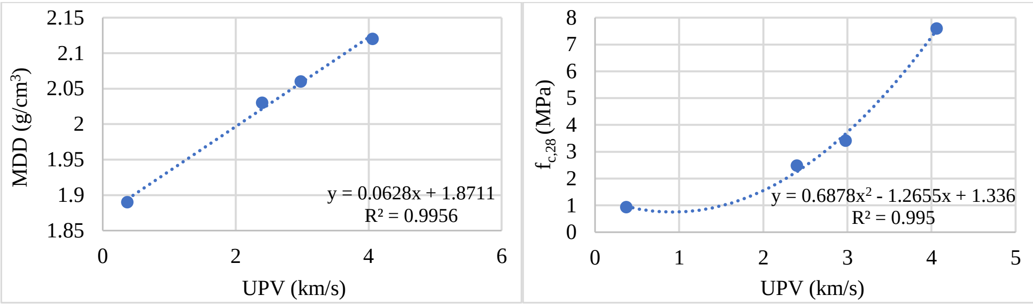
UPV measurement is a non-destructive test, it is simple to perform and it is in use for classification of the quality of concrete for a long period now (excellent quality concrete with UPV values > 4,5 km/s and very poor quality concrete with UPV < 2 km/s (Guidebook on non-destructive testing of concrete structures 2002)). A similar analogy was used in previous research where UPV ranging 2-3,2 km/s indicated a material of satisfactory compressive strength (2-6 MP) (Barišić, Dimter, and Rukavina 2016). Within this research, a similar result is observed with UPV less than 2 km/s indicating insufficient $f_{c,28}$ (less than 2 MPa) for high traffic purposes. In Figure 5, the correlation between UPV and MDD (a) and compressive strength (b) is presented and a strong correlation is noted. Although only a limited number of samples and results are presented, this is a good basis for further research.



a) b)

Figure 5. Correlation between UPV and maximum dry density (a) and UPV and compressive strength (b)

4. Conclusion

This preliminary study aimed to obtain an initial input on the influence of various amounts of crumb rubber on the mechanical properties of cement bound base course (CBC) mixtures for heavy traffic load pavement application. From the presented laboratory test results, the following conclusions can be made:

- addition of rubber results in a drop of maximum dry density, optimal water content, ultrasound pulse velocity and compressive strength of cement bound aggregate for pavement base layer
- drop in dynamic modulus of elasticity value by rubber addition indicates a less stiff material for CBC construction
- fine aggregate fraction could be replaced by rubber to 30 vol. % while maintaining the minimum value of compressive strength on 2 MPa
- for the next phase of the research, the influence of rubber replacement level depending on different cement content and more detailed insight into elastic behaviour and crack occurrence reduction is to be investigated.

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Author Contributions

MZ (Matija Zvonarić) and IB conceived this study, MZ (Matija Zvonarić) conducted laboratory tests, TD, IB and MZ (Martina Zagvozda) were responsible for data analysis and article conceptualization.

Disclosure statement

The authors declare no conflict of interest.

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