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Comparative study of the mechanical behaviour of bitumen and cement-dominated mixtures with reclaimed asphalt

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Abstract. Bitumen emulsion-based recycling is commonly used maintenance treatment in rehabilitation of low and medium volume roads in Europe. Nevertheless, the wide range of climatic conditions across Europe resulted in various concepts of mixtures and requirements adopted for various local conditions. In this regard, the main parameter to distinguish between the mixture concepts is bitumen to cement ratio. The article presents the comparison of the results of mechanical properties for different concepts of cold recycled mixtures designed with either bitumen or cement having the dominant role in the mechanical behaviour. In both cases Portland cement CEM I and bituminous emulsion C60B5 were used as the binding agents. The cold recycled mixtures were designed to contain at least 70 % of reclaimed asphalt. The combinations of binding agents were selected based on the respective requirements. Mechanical properties were expressed by the indirect tensile strength, failure strain, and stiffness modulus. Test were conducted in the temperatures of 5 and 20 °C for the curing periods of 7 and 28 days. The comparison showed that the mixtures with the higher content of cement reach much higher stiffnesses and their performance even resembles cementitious materials in case of stiffness and strength development. In contrast to this, the behaviour of bitumen dominated mixtures, especially at lower curing stages, is within the common requirements but also tend to have much higher strains at failure.

Keywords: Bitumen emulsions, Cement, Reclaimed asphalt, Indirect tensile testing, Cold recycling.

1 Introduction

Local old asphalt pavements, especially low volume roads, very often requires reconstruction up to the base layer. One of the most suitable recycling technologies in this case is deep cold recycling [1,2,3,4,5,6]. Despite its common usage, there is no clear methodology of design and evaluation of the mixtures made using old pavement materials. While the procedures in different countries seem very similar, each country have its local regulations influencing the final recipe [7], especially regarding the relations between bitumen emulsion and cement as co-binders [8]. Also, requirements for cold recycled mixtures differ depending on the climatic conditions. Paper presents comparison of two different approaches for design of cold recycled mixtures: one for Polish conditions with hot summers, very cold winters, numerous freeze-thaw cycles and often work in saturated conditions and one for Serbian conditions with much milder conditions during the cold period of year. In the both approaches, the mixtures are designed for the traffic load of about 7.3 million 100-kN axes (over 20 years).

The objective of this research is a comprehensive study of the mechanical behaviour of asphalt mixtures with very high fraction of reclaimed asphalt (RA) considering two different approaches to the formulation of the bitumen emulsion-cement composite. The influence of the composition of the co-binder system is mainly evaluated from the aspect of the dominance of one binder over the another.

2 Materials and methods

Two different types of cold recycled mixtures (cement- and emulsion- dominated) were tested by considering three combinations of bitumen and cement. The composition of mixtures, their basic properties, and grading curves presented in Table 1.

The Polish mixtures were prepared using the commonly applied Portland CEM I 32.5 R and cationic slow setting bituminous emulsion C60B5 dedicated for cold recycling. Specimens are prepared at optimum fluid content, determined by means of modified proctor method. Cylindrical specimens of (63.5 ±3.5) mm in height and (101 ± 2) mm diameter are compacted using Marshall hammer (2 times 75 blows) and performed moulds. The specimens were tested at 5 and 20 °C.

On the other hand, the Serbian mixtures were prepared using the with the Portland cement CEM I 42.5 N also with the cationic slow setting bituminous emulsion C60B1. Cylindrical specimens of 125 mm in height and 150 mm in diameter are compacted statically from both sides [9]. The distribution of the reclaimed asphalt and virgin aggregate across sieve sizes is shown in Figures 1 and 2. Because of their ductility, the specimens were tested at 5 °C only [10, 11]. All specimens are tested after 7 and 28 days of curing at the temperature of (20±2) °C and the relative humidity of 40 to 60%.it is assumed that all the possible cement hydration is accomplished within 28 days, and that no significant change in mechanical properties occurred by then.

The mechanical properties of both groups of specimens were evaluated by the indirect tensile stiffness modulus (*ITSM*) according to EN 12697-26 and strength (*ITS*) according to EN 12697-23 using the IT-CY method. The horizontal strain at failure was evaluated for the second group of specimens only because of their higher content of bitumen, and thus, higher expected ductility. Specimens were tested in strain-controlled mode at the temperatures of 5 and 20 ºC. Before the testing, specimens were conditioned for 4 h at the test temperature. The results were evaluated using a pre-defined value of the Poisson's ratio of 0.3.

Table 1. Tested materials.

Property	Value					
	Poland			Serbia		
	C2E2	C3E2	C4E2	C1.5E5	C1.5E6	C1.5E7
Percentage passing sieve (%)						
63.0	100.0	100.0	100.0	100.0	100.0	100.0
31.5	97.3	97.3	97.3	98.8	98.8	98.8
16	76.8	76.8	76.8	75.8	75.8	75.8
8	58.5	58.5	58.5	64.0	64.0	64.0
4	43.5	43.5	43.5	44.0	44.0	44.0
2	33.2	33.2	33.2	31.9	31.9	31.9
1	24.3	24.3	24.3	27.5	27.5	27.5
0.5	17.4	17.4	17.4	23.0	23.0	23.0
0.125	3.4	3.4	3.4	10.3	10.3	10.3
0.063	1.3	1.3	1.3	7.0	7.0	7.0
Mineral composition						
RA content (%)	70	70	70	80	80	80
Virgin 0/2 (%)	12	12	12	3.1	3.1	3.1
Virgin 0/32 (%)	18	18	18	17.4	17.4	17.4
Cement content (%)[a)]	2	3	4	1.5	1.5	1.5
Emulsion content (%)[a)]	2	2	2	5	6	7
Air voids after 28 days (%)	14.3	14.9	13.9	11.8	8.6	9.1

a) Percentage given by mass of mineral mixture

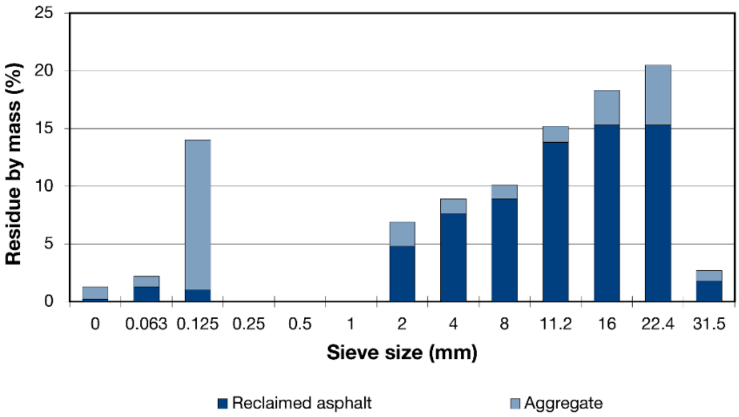

Fig. 1. Distribution of the reclaimed asphalt and virgin aggregate across the mineral mixture as a function of sieve residue for the mixtures C2E2, C3E2, and C4E2.

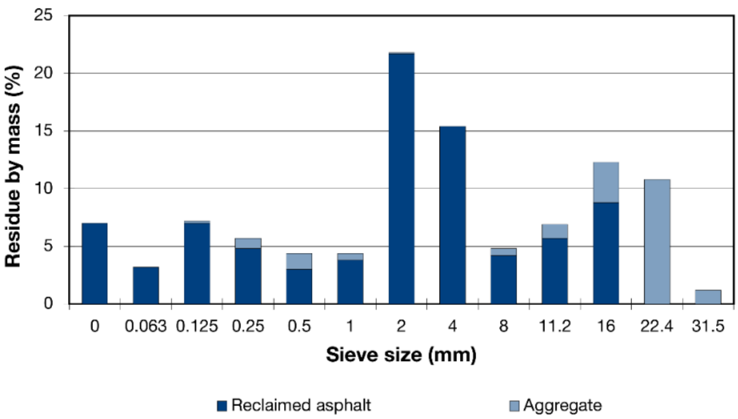

Fig. 2. Distribution of the reclaimed asphalt and virgin aggregate across the mineral mixture as a function of sieve residue for the mixtures C1.5E5, C1.5E6, and C1.5E7.

3 Results and discussion

The results of the mechanical properties are shown in Table 2. The ratios of the obtained results between the curing periods and curing temperatures are shown in Table 3.

It can be observed from the results that the two concepts demonstrated substantially different mechanical performance. The first group of specimens had a clearly cement-dominated behaviour very high stiffness modulus approaching the upper limit of 7000 MPa at 5 °C after 28 days, which is close to cementitious materials [12]. In the period of 7 days after compaction mixtures obtained around 60 to 80 % of final value. Similar development of mechanical properties with time after compaction is visible for cement concrete and cement bound mixtures used in pavement construction.

On the other hand, the second group of specimens with the considerably higher bitumen to cement ratio had stiffness modulus in the range from 3000 to 7000 MPa which is considered general boundaries for emulsion-based materials [13]. The failure stain of the specimens C1.5E5 was slightly above 2.5 ‰ which can be consider the lowest limit for of the deformation at failure for bituminous materials. The development of mechanical properties is slower than in the case of cement-dominated materials. After 7 days mixtures presented only from 48 to 70% of the final values.

In all cases, strength and stress directly increase with increase of the bitumen to cement ratio. What is interesting the influence of bitumen (from bituminous emulsion and RA) was still significant, as the obtained properties were very dependent on the test temperature. By decreasing the test temperature from 5 to 20 ºC, the specimens obtained values increased almost twice. However, the difference between the two test temperatures is getting less prominent over time after compaction and with higher amount of cement, which suggests the domination of the hydraulic bonds.

Table 2. Laboratory test results.

Property	Value					
	C2E2	C3E2	C4E2	C1.5E5	C1.5E6	C1.5E7
ITSM at 5 °C (MPa)						
7 days	3491	5534	7109	2425	2080	1640
28 days	5867	7441	8615	4291	4315	3278
ITSM at 20 °C (MPa)						
7 days	1672	2737	3919	—	—	—
28 days	2819	3902	5632	—	—	—
ITS at 5 °C (MPa)						
7 days	0.56	0.73	1.04	1.00	1.12	1.14
28 days	0.64	0.92	1.18	1.38	1.56	1.56
ITS at 20 °C (MPa)						
7 days	0.29	0.40	0.60	—	—	—
28 days	0.36	0.57	0.77	—	—	—
Failure strain, (‰)						
7 days	—	—	—	4.054	4.519	7.685
28 days	—	—	—	2.830	3.251	4.322

Table 3. Properties as ratio in comparison to properties for 28 days of curing.

Property	Value					
	C2E2	C3E2	C4E2	C1.5E5	C1.5E6	C1.5E7
Ratio between the values for 7 to 28 days						
ITSM, 5 °C	0.60	0.74	0.83	0.57	0.48	0.50
ITSM, 20 °C	0.59	0.70	0.70	—	—	—
ITS, 5 °C	0.88	0.79	0.88	0.72	0.72	0.73
ITS, 20 °C	0.81	0.70	0.78	—	—	—
Ratio between the values for 5 and 20 ºC						
ITSM, 7 days	2.09	2.02	1.81	—	—	—
ITSM, 28 days	2.08	1.91	1.53	—	—	—
ITS, 7 days	1.93	1.83	1.73	—	—	—
ITS, 28 days	1.78	1.61	1.53	—	—	—

4 Conclusions

The comparison showed that the mixtures with the higher content of cement, as expected, reach much higher strengths and stiffnesses and their performance even resembles cementitious materials in case of stiffness and strength development. In contrast to this, the behaviour of bitumen dominated mixtures, especially at lower curing stages, is within the common requirements but also tend to have much higher strains at failure. The results showed the very significant effect of the quantitative relations between bitumen and cement in the system on the overall mechanical behaviour.

This points out the need for a systematic characterisation of the volumetric composition of these materials across length scales, necessary for the fundamental understanding of the eco-binder system. Creating the single framework and system of criteria for the distinction between bitumen and cement-dominated mixtures is of a crucial importance for the adequate mechanical analysis and design of in-service pavements. Further research should be focused on the more intrinsic evaluation of the spatial relation of these binders on the micro scale and fundamental evaluation of their physico-chemical interaction. These relations and their changes with time should be studied from the perspective of rheology, micromechanics, microstructure and chemistry.

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