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The influence of cement type on early properties of cold in-place recycled mixtures

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Abstract. Cold in-place recycling is a commonly used maintenance treatment in rehabilitation of low and medium volume roads in Poland. Typically, two types of binding agents are used – cement and bituminous emulsion (or foamed bitumen). Due to the harsh Polish climate with many freeze/thaw cycles and frequent occurrence of saturated conditions, the used amounts of cement are higher than those commonly used in warmer parts of Europe. While there is usually only one type of bituminous emulsion dedicated for cold recycling on the market, there are numerous types of cements, which differ in chemical composition and properties. The conducted research presents possible development of cold recycled mixture properties over curing time, taking into account the type of cement used. Two types of cement were tested in laboratory investigation – common Portland CEM I 32.5 R cement and Portland-fly ash CEM II 32.5 B-V cement with longer setting time. Cold recycled mixtures were designed with the same composition and amount of binding agents, but differed in the type of cement used. For both mixtures, indirect tensile strength and modulus were tested after 7, 28 and 90 days of curing in laboratory conditions. The laboratory tests confirmed lower values of strength and modulus for the fly ash cement after 7 and 28 days in comparison to the typical cement, but after 90 days the properties of both tested mixtures presented similar values. If the overall predicted fatigue life and long-term mechanical properties are the same, the use of slow-setting cements may result in reduction of reflective cracking on the surface of the pavement. In the case of low and medium volume roads, where there is no need for fast paving of the asphalt layers and more time may be allowed for the cold-recycled mixture to achieve the required initial strength, slow-setting cements should be considered as a viable treatment for reduction of the risk of reflective cracking.

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

1 Introduction

Low and medium volume roads in Poland are often in poor condition. One of the typically used maintenance treatment in rehabilitation using cold in-place recycling [1, 2] with two binding agents– cement and bituminous emulsion (or foamed bitumen). In Poland the amount of cement used in-place recycling is higher than used in warmer parts of Europe [3,4]. It resulted from experience with harsh climatic conditions characterized by numerous freeze/thaw cycles and frequent occurrence of saturated state. While on the Polish market there is usually only one type of bituminous emulsion dedicated for cold recycling, there are numerous types of cements, which differ in chemical composition and properties [11]. In most cases typical CEM I Portland cement is used for cold recycling [3-8], regardless of the region of usage. Only isolated studies [9,10] sought to analyse the possibility of use of other types of cement, including slow-setting cement. The domination of CEM I Portland cement is commonly related to the requirements and the construction schedule considerations. The conducted research was designed to evaluate the possibility of obtaining a cold recycled mixture that can develop its properties over a longer time of curing, without overall negative effect during the construction and service phase.

Classification of cement is based on its main constituents. In Poland, the most commonly used cement type for cold recycled mixtures is the Portland cement CEM I, which consists mostly of clinker (95–100%). The EN 197-1 standard also allows the use of Portland-composite cements, that may contain blastfurnace slag, silica fume, pozzolana, fly ashes or limestone. They are classified as CEM II main type. Cements with lower clinker content, such as blastfurnace cement (CEM III) or pozzolanic cement (CEM IV), may be used as well [11]. The content of various constituents affects the setting time, the rate of strength development and the final strength of the cement. The type of cement also affects the heat of hydration during setting. While the use of CEM I cements ensures higher early strength of the mixture, it may also lead to higher number of shrinkage cracks, due to higher heat of hydration and higher shrinkage, as compared to mixtures that contain CEM II type cements, which exhibits a lower rate of strength development, and, consequently, lower shrinkage and lesser tendency towards initiation of transverse cracks

2 Materials and methods

Six different cold recycled mixtures with two different types of cement – Portland CEM I 32.5 R cement and Portland fly-ash CEM II 32.5 B/V cement (containing clinker and siliceous fly ash) – were tested in the study (three different mixtures for each type of cement). The composition of the tested cements is given in Table 1.

The cold recycled mixtures were composed of: 70% reclaimed asphalt pavement, 15% virgin fine aggregate and 15% virgin coarse aggregate. The influence of cement was assessed for a set amount of emulsion (E = 4%) and three different amounts of cement (C = 1%, 2% or 3%). The properties and compositions of the tested mixtures are presented in Table 2. Mixtures were described with abbreviations taking into account the content of binding agents (e.g. C1E4 meaning 1% cement and 4 % emulsion).

Table 1. Composition of the tested cements

Cement	Main constituents		Minor additional constituents
	Clinker	Siliceous fly ash	
CEM I	95–100 %		0–5 %
CEM II B/V	65–79 %	21–35 %	0–5 %

Table 2. Tested materials

Property	Mixture designation*					
	C1E4 (a)	C2E4 (a)	C3E4 (a)	C1E4 (b)	C2E4 (b)	C3E4 (b)
Gradation [mm], [%]						
31.5	100.0	100.0	100.0	100.0	100.0	100.0
16	86.1	86.1	86.1	86.1	86.1	86.1
8	54.1	54.1	54.1	54.1	54.1	54.1
4	36.8	36.8	36.8	36.8	36.8	36.8
2	27.6	27.6	27.6	27.6	27.6	27.6
1	20.1	20.1	20.1	20.1	20.1	20.1
0.5	12.1	12.1	12.1	12.1	12.1	12.1
0.125	2.6	2.6	2.6	2.6	2.6	2.6
0.063	1.3	1.3	1.3	1.3	1.3	1.3
Cement content [%]	1	2	3	1	2	3
Emulsion content [%]	4	4	4	4	4	4
Air voids [%]	10.4	11.9	10.4	12.4	12.4	11.9
Type of cement	CEM I 32.5R			CEM II B/V 32.5R		

* cold recycled mixtures: (a) with CEM I 32.5 R, (b) with CEM II B/V 32.5 R

For the purpose of the analysis, two laboratory test were selected: Indirect Tensile Stiffness Modulus Test (ITSM) according to EN 12697-26 (load time: 124±4 ms, target horizontal deformation: 5 μm) and Indirect Tensile Strength (ITS) according to EN 12697-23 (displacement rate: 50 mm/min). The temperature of the test was selected as +5°C. The tests were conducted for three curing ages: 7 days, 28 days and 90 days after compaction. In each case three separate specimens were tested.

3 Results and discussion

The results of the stiffness modulus and strength tests for all the tested mixtures are presented in Table 3 as mean values with coefficients of variation (CoV), which reflect the scatter of the results. The tests were conducted 7, 28 and 90 days after compaction of the specimen.

Table 3. Laboratory test results

	Mixture designation*						
Property	C1E4 (a)	C2E4 (a)	C3E4 (a)	C1E4 (b)	C2E4 (b)	C3E4 (b)	Require-ments [1]
ITSM, +5°C							
7 days, mean, MPa	2279	3999	5767	1769	2262	3397	-
7 days, CoV, %	12.7	5.9	4.6	18.7	8.0	5.2	
28 days, mean, MPa	3022	6012	8792	2215	3368	6948	2000÷7000
28 days, CoV, %	1.7	5.8	1.5	26.0	13.1	5.3	
90 days, mean, MPa	5137	8177	11912	3178	5716	10286	-
90 days, CoV, %	5.8	1.4	9.1	20.4	13.4	8.8	
ITS, +5°C,							
7 days, mean, MPa	0.42	0.71	0.85	0.47	0.47	0.57	0.5÷1.0
7 days, CoV, %	13.9	8.1	7.5	2.2	8.9	12.1	
28 days, mean, MPa	0.46	0.77	1.08	0.47	0.64	0.88	0.7÷1.6
28 days, CoV, %	9.7	6.9	3.2	3.8	3.1	7.2	
90 days, mean, MPa	0.71	1.07	1.52	0.63	0.79	1.39	-
90 days, CoV, %	2.1	4.2	4.6	14.0	22.1	6.0	

* cold recycled mixtures: (a) with CEM I 32.5 R, (b) with CEM II B/V 32.5 R

As shown in Table 3, a properly designed cold recycled base should contain at least 2% of CEM I cement or at least 3% of CEM II B/V cement. High requirements for Poland [12] regarding stiffness modulus and strength are related to harsh climatic conditions, under which from November until April the pavement is subjected to frost and numerous freeze/thaw cycles in water-saturated state. Moreover, a layer constructed from cold recycled material should exhibit mechanical properties sufficient to enable further paving works as soon as possible. The aforementioned conditions result in high amounts of required cement.

While the relatively high strength requirements and usage of CEM I cement with high clinker content are forced by the climatic conditions, they consequently lead to occurrence of reflective cracking [1]. Other cements, which are less susceptible to shrinkage cracking (CEM II), do not always enable obtaining of satisfactory short-term strength parameters (after 7 or 28 days), when used in the same quantities as CEM I. In order to gain insight into their performance in longer perspective, the third test was performed 90 days after compaction. It proved that after the longer period both cement types exhibited comparable results, despite the considerable differences after 7 and 28 days.

To compare the development of mechanical properties in time for both types of cement, the results in Table 4 are presented as ratio compared to the values for 28 days of curing. In the first case, values were compared to those obtained for the same type of cement after 28 days. In the second case, the results for CEM II were compared to those obtained for CEM I cement after 28 days.

Table 4. Properties as ratio in comparison to properties for 28 days of curing

Property		Mixture designation					
		C1E4 (a)	C2E4 (a)	C3E4 (a)	C1E4 (b)	C2E4 (b)	C3E4 (b)
		CEM I/CEM I$_{(28\ \text{days})}$ ratio			CEM II/CEM II$_{(28\ \text{days})}$ ratio		
ITSM +5°C	7 days	0.75	0.67	0.66	0.80	0.67	0.49
	28 days	1.00	1.00	1.00	1.00	1.00	1.00
	90 days	1.70	1.36	1.35	1.43	1.70	1.48
					CEM II/CEM I$_{(28\ \text{days})}$ ratio		
ITSM +5°C	7 days				0.59	0.38	0.39
	28 days				0.73	0.56	0.79
	90 days				1.05	0.95	1.17
		CEM I/CEM I$_{(28\ \text{days})}$ ratio			CEM II/CEM II$_{(28\ \text{days})}$ ratio		
ITS +5°C	7 days	0.91	0.92	0.79	1.00	0.74	0.65
	28 days	1.00	1.00	1.00	1.00	1.00	1.00
	90 days	1.53	1.39	1.40	1.32	1.23	1.58
					CEM II/CEM I$_{(28\ \text{days})}$ ratio		
ITS +5°C	7 days				1.02	0.61	0.53
	28 days				1.02	0.83	0.81
	90 days				1.35	1.02	1.28

The development of mechanical properties in the presented study for both types of cement is similar: after the initial rapid build-up it slows down after 28 days, reaching the maximum value after 90 days. In the case of stiffness modulus, while the development process is the same for both cements (around 60–70% after 7 days and around 130–170% after 90 days) the absolute values for CEM II B/V cement are much lower. Mixtures containing this cement needed almost 90 days to reach the stiffness modulus values that CEM I mixtures reached after 28 days of curing. As for strength, initial increase is much faster for CEM I cement, which obtains almost its final strength (80–90% of strength) as soon as after 7 days. In the case of mixtures with CEM II B/V cement, the strength values after 7 days were much lower; only after 90 days they reached levels comparable do those obtained by the CEM I mixtures.

4 Conclusions

Laboratory tests after 7 and 28 days confirmed lower values of strength and modulus for Portland-fly ash cement CEM II B/V in comparison to typical Portland cement CEM I, but after 90 days the properties of both tested mixtures presented similar values. The performed tests show that it is possible to obtain the same level of strength parameters using both types of cement. The Portland-composite cement only requires longer setting time. Taking into account the shrinkage that occurs during setting, it is advisable to use Portland-composite cements, since their shrinkage is lower and, in consequence, the risk of cracking is decreased. If the overall predicted fatigue life and long-term mechanical properties are the same, the use of slow-setting cements may result in reduction of reflective cracking on the surface of the pavement. In the case of low and medium volume roads, where there is no need for fast paving of the asphalt layers and more time may be allowed for the cold-recycled mixture to achieve the required initial strength, slow-setting cements should be considered as a viable treatment for reduction of the risk of reflective cracking.

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References

1. Dołżycki B., Jaskuła P.: Review and evaluation of cold recycling with bitumen emulsion and cement for rehabilitation of old pavements. Journal of Traffic and Transportation Engineering 6(4), 311-323 (2019).
2. Chomicz-Kowalska A., Stepien J.: Cost and eco-effective cold in-place recycled mixtures with foamed bitumen during the reconstruction of a road section under variable load bearing capacity of the subgrade. Procedia Engineering 161, 980–989 (2016).
3. Bocci M., Grilli A., Cardone F., Graziani A.: A study on the mechanical behaviour of cement–bitumen treated materials. Construction and Building Materials 25, 773–778 (2011).
4. Meocci M., Grilli A., La Torre F., Bocci M.: Evaluation of mechanical performance of cement–bitumen-treated materials through laboratory and in-situ testing. Road Materials and Pavement Design 18(2), 376-389 (2017).
5. Kavussi A., Modarres A.: A model for resilient modulus determination of recycled mixes with bitumen emulsion and cement from ITS testing results. Construction and Building Materials 24, 2252-2259 (2010).
6. Dolzycki B., Jaczewski M., Szydlowski C.: The long-term properties of mineral-cement-emulsion mixtures. Construction and Building Materials 156, 799-808 (2017).
7. Buczyński P., Iwański M.: Complex modulus change within the linear viscoelastic region of the mineral-cement mixture with foamed bitumen. Construction and Building Materials 172, 52-62 (2018).
8. Raschia S., Graziani A., Carter A., Perraton D.: Laboratory mechanical characterisation of cold recycled mixtures produced with different RAP sources. Road Materials and Pavement Design 20(sup1), 233-246 (2019).
9. Baghini M. S., Ismail A., Bin Karim, M. Rehan.: Evaluation of cement-treated mixtures with slow setting bitumen emulsion as base course material for road pavements. Construction and Building Materials 94, 232-336 (2015).
10. Shaowen D.: Effect of curing conditions on properties of cement asphalt emulsion mixture. Construction and Building Materials 164, 84–93 (2018).
11. Peukert S.: Cementy powszechnego użytku i specjalne. Polski Cement, Kraków 2000
12. Dołżycki B.: Polish experience with cold in-place recycling, Bestinfra 2017, IOP Conference Series: Materials Science and Engineering 236, 012089.