COLD RECYCLED MIXTURES FOR BINDER COURSES - LABORATORY EVALUATION OF MECHANICAL PROPERTIES

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Abstract

Cold recycled mixtures composed with cement and bituminous emulsion are nowadays commonly used material for base layer. Typical pavement with cold recycled mixtures usually consists of two asphalt courses (wearing and binding course) constructed over cold recycled base. Therefore the next step in cold recycling is possibility of design of binding courses with recycled materials, but with potential to obtain high quality mixtures similar to commonly used asphalt concretes. In this case, typical new pavement structure would be designed as two cold recycled mixtures (for base and binding course) covered by wearing course. This publication presents both basic and advanced laboratory results for cold recycled binding course. Cold recycle binding course is characterized by more strict requirements for base material gradation and more strict ranges for possible properties. Also the composition of binding agents is selected to be as similar as for typical asphalt concretes. In laboratory following test were performed: volumetric properties, resistance to water and frost action, viscoelastic properties (dynamic modulus, phase angles) and resistance to fracture in SCB test. For comparison, the same test were performed for asphalt concrete for binder course and for selected test also for cement bound mixtures. Obtained results indicate that cold recycled mixtures for binder course are located between typical asphalt concretes and cement bound mixtures, characterizing by both high bearing capacity and sufficient viscoelastic properties. In the case of resistance to water and frost, cold recycled mixtures are characterized by ratio between 75-85 %. Cold recycled mixtures showed good fracture resistance results in SCB test in comparison to other tested mixtures. Laboratory stage of research confirmed very good properties of cold recycled binding course and open possibility for further steps to construct and evaluate the designed mixtures on real life conditions on trial section in real environmental conditions.

Keywords: cold recycled mixtures, binder course, mix design, Cold bitumen emulsion mixtures, dynamic modulus, fracture test

1 Introduction

1.1 Cold recycling of asphalt pavements

Cold recycling is a technology which allows to reuse materials from the old and deteriorated roads. Due to its relatively simple technology and cheap costs it is very often used on local low volume roads in which tar materials were utilized. In Poland this technology is used since the 90s, when many local roads were processed into base layers with high bearing capacity. In most of the cases cement and bituminous emulsion were used as binding agents. Now it is common technology for rebuilding of old low trafficked roads [1].

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Among the main advantages of the technology one can mention the possibilities to: a) reuse the material from roads in very bad technical conditions, b) utilize the layers with tar binder in an environmental friendly way, c) improve the resistance to frost heave. In most cases the old pavement structure has to thin construction to provide the sufficient resistance and d) homogenize the properties of the pavement, which are very varied due to different constructions and history of damage repair.
Pavement with cold recycled bases were introduced in 2014 as typical pavement structures in Polish catalogue of typical flexible and semirigid pavements [2, 8]. Catalogue [2, 8] presents the constructions with cold recycled bases for roads of low and medium traffic (traffic categories KR1-KR4). The limitation for traffic categories was introduced due to high heterogeneity of the material properties which does not comply with requirements for heavy traffic categories.
Cold recycled mixtures can be either prepared on the existing construction site (in-place) or in stationary mixing plant (in-plant). Recently the most often way of preparation of the mixture is with using mobile stationary plant of KM 200 plant placed near the construction site, as in most of the road sections high attention is put to the providing of sufficient frost heave resistance and correction of the road geometric properties. In the latter case the pavement structure is treated as a new construction with one of the layers prepared using cold recycling.

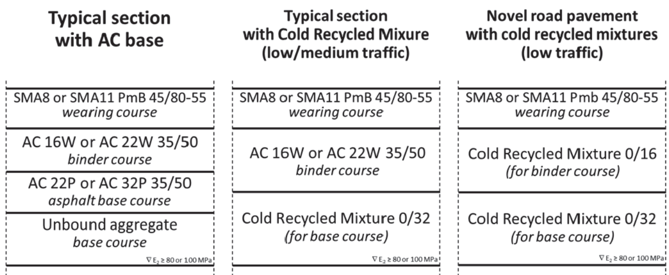

Figure 1 Pavement structures – typical and with cold recycling mixtures in wearing course

Preparation of the cold recycled mixture in stationary plant allows better control of the base materials and provides more homogeneous final product. This advantages resulted in using this technology to other pavement courses than only base course – such as cold recycled binder course. The conception and preliminary results of this usage were presented in previous CETRA conference, [3].
Figure 1 presents the comparison of commonly used pavement structures for low trafficked roads in Poland (up to 500000 of 100 kN axles) with novel conception of pavement structure with using cold recycled mixture used in binder course.
Previous research [3] showed that the cold recycled mixture of 0/16 gradation used for binder course achieves properties stated for typical cold recycled mixture. But while the basic properties were sufficient for the base course, it is not enough when used in binder course. In higher pavement courses more attention should be put to environmental properties and resistance to cracking. Those two properties are the main aspect presented in this publication.

1.2 Impact of local climatic and traffic conditions on cold recycled mixture properties

Requirements stated for cold recycled mixture for all courses strongly depend on the climatic conditions. High values of mechanical properties stated for mixtures are the results of two factors: construction traffic and winter temperatures. While the first one is the same for most of the countries, which uses the same construction equipment, the second factor strongly differs even across the Europe. For now only two European countries have experiences with cold recycling for binding course – Italy [3, 4, 5] and Poland [3]. In Italy the climate is quite mild - the mean winter temperatures are in most regions above 0 °C, without many 0 °C transitions. On the other hand in Poland, typically mean winter temperature are either slightly above 0 °C or below 0 °C with many 0 °C transition [7]. Therefore the higher strength of the material is required to sustain such harsh conditions. This results in composition of the mixture, which requires higher amount of binder, especially cement in comparison to the Italy specification. Also high requirement for resistance to water and frost action comes from harsh winter conditions.

1.3 Pavement cracking

Cold recycled mixtures use two binding agents – bituminous emulsion and Portland cement. The suggested amount of the respective binders is 3-6 % in the case of emulsion and 1-4 % in the case of cement [9]. Due to the required mechanical properties the amound of cement in most cases is around 3 % or even more. Such amount of cement may cause increased susceptibility to reflective cracking. The cold recycled mixtures presents lower resistance to cracking in comparison to the asphalt concrete and cement concrete, but significantly higher than in the case of cement bound aggregate, despite higher amount of cement used in cold recycled mixtures [10].

2 Materials and methods

2.1 Cold recycled mixture for binding course

As cold recycled mixtures are typically used in Poland for base and sub-base courses there are no specifications or regulations for designing cold recycled mixtures for binder course. Procedure for base courses was utilized with appropriate changes. Firstly CRM grading curve limits were developed. The proposed curves envelopes are presented in Figure 2.

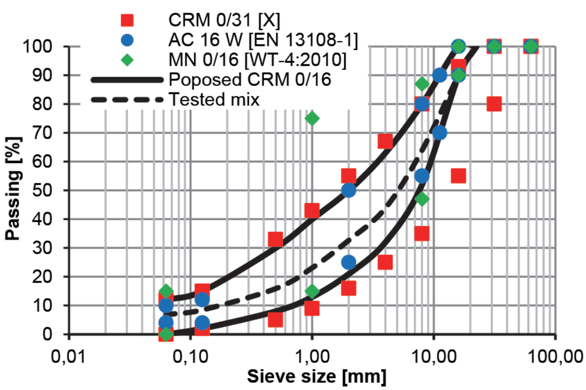

Figure 2 Proposed grading curves limits for CRM 0/16

The composition of the mineral mixture was determined based on the Polish guidelines [9]. The cold bitumen emulsion mixtures were composed of 57.5 % reclaimed asphalt pavement (22 RA 0/16), 9.3 % fine aggregate (0/2 G_f85 f16) and 23.3 % all-in aggregate (0/31.5 G_A90 f16) with 3 % cement (CEM I 32.5R) and 7 % bitumen emulsion (C 60 B 10 ZM/R). The 7 % emulsion content means the mix contains 4.2 % asphalt, which is somewhere in between the traditional asphalt sub-base (3.9 %) and the binder course (4.5 %). Designed mixture allow obtaining a dry density of 1914 kg/m^3 with optimum water content 7.9 % (including water and binder from emulsion), an indirect tensile strength at 5 °C of 0.78 MPa and an indirect tensile stiffness modulus at 5 °C of 4 921 MPa after a curing period of 28 days at 20 °C [3].

2.2 Laboratory investigation

Dynamic moduli and phase angles were determined according to AASHTO TP79 standard. Test temperatures were selected as 4, 20 and 40 °C in a strain-controlled mode. The gauge length was 70±1 mm, for all three LVDT sensors attached to the side of the specimen. The test frequencies were 25, 20, 10, 5, 2, 1, 0.5, 0.2 and 0.1 Hz for temperatures up to 20 °C. For the temperature of 40 °C additionally frequency of 0.01 Hz was tested. Results was presented as Black diagrams (dynamic moduli vs phase angles) and compared with typical cold recycled mixture for base course and asphalt concrete AC 16W for binding course. All presented results are presented for the period of 28 days of curing in laboratory conditions.
Resistance to water were investigated using three conditioning methods: (1) 14 days at room temperature/14 days immersed in water, sample tested at 5 °C, like CRM 0/31 for base course according to [9]; (2) 72 h in water bath at 40 °C/16 h in freezer at -18 °C/24 h in water bath at 25 °C, sample tested at 25 °C, like asphalt mix AC 16 W according to Polish requirements [11], (3) 14 days at room temperature/14 days immersed in water, sample tested at 25 °C. Indirect tensile strength tests were performed for each case (rate of deformation: 50 mm/min).
The Semi-Circular Bending Test (SCB) was conducted to evaluate fracture properties of tested mixtures. The test was based on the procedure described in standard EN 12697-44 [12]. Resistance to fracture K_{IC} and The critical value of the J-integral that characterizes the strain energy release rate during crack propagation was calculated from the relationship between the change in notch length that was cut in the bottom plane of the sample and the change of strain energy was measured to maximum value of load (pre-peak). Specimen with 10 mm, 20 mm and 30 mm notch depth were tested at 10 °C with 1 mm/min deformation rate.

3 Results and discussion

3.1 Viscoelastic properties

Viscoelastic properties of cold recycled mixture for binding course determined using SPT are presented on figure 3 and for selected conditions in table 1. The obtained results are compared with those obtained in previous results for cold recycled mixtures for base course [6] and asphalt concretes for binder course [13].

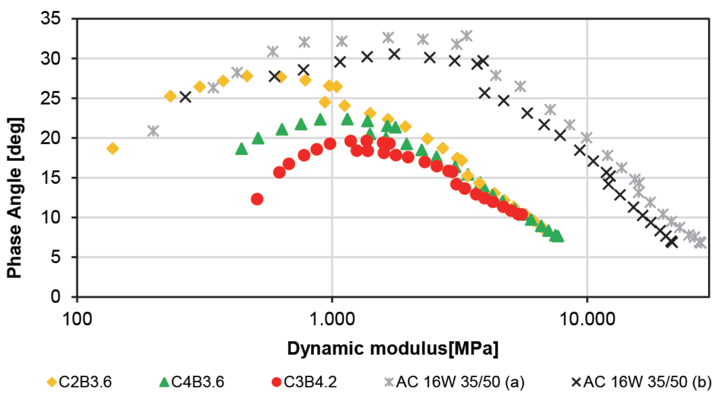

Figure 3 Black diagram on the basis of SPT test

Following properties of cold recycled mixtures for binding course are visible: the dynamic moduli have the lowest values for low temperatures, but have the highest values for high temperatures; in the medium temperatures the obtained values are similar for all cold recycled mixtures; the temperature dependence for cold recycled mixtures for binder course is the lowest among all tested mixtures – the range between the highest and lowest determined moduli is the lowest and the determined maximum (for 40 °C) phase angle is the lowest among all tested mixtures. It should be also noted that the values obtained for cold recycled mixtures differs strongly from typical asphalt concrete for binder course. In all cases obtained dynamic moduli for cold recycled mixtures for the design temperatures are around 3-4 times lower than those obtained for typical asphalt concretes (for all temperatures), but at the same time the values of phase angles for cold recycled mixtures are around 2 times lower (especially in highest test temperatures). Due this fact in case of pavement design, the designed thickness of the cold recycled binding course should be slightly higher, but on the other hand, such mixture will be more resistant to permanent deformation. It should be also noted that this disproportions for dynamic moduli will decrease with time. It could be assumed on the base of previous tests [6], that the diffrerenc will slowly diminishes with time, due to hydration of cement. Previous test proved that the yearly increase of dynamic modulus is around 500 MPa, therefore selection of the representive moduli for design will be very important issue in next years.

Table 1 Viscoelastic properties determined using SPT test, for temperature of 20 °C

Property	**Dynamic modulus** [MPa] **phase angle** [°]				
Frequency	25	10	5	1	0.1
C3B4.2(0/16)	2957 15,77	2569 16,46	2305 16,99	1777 17,85	1248 18,42
AC 16W 35/50 (b)	11882 15,67	9350 18,47	7830 20,34	5820 23,14	3907 29,72

3.2 Resistance to water and frost action

Test results are presented in Table 2.

Table 2 Resistance to water and frost action results

Conditioning method	**ITS without conditioning** [MPa]	**ITS after conditioning** [MPa]	**ITSR** [%]	**Requirements**
Cold recycled mixture for binder course				
1, T = 5°C	1.08	0.81	75	80 [9]
2, T = 25°C	0.42	0.35	83	80 [11]
3, T = 25°C	0.42	0.36	86	-
Asphalt concrete for binder course				
2, T = 25°C	0.97	0.85	88	80 [11]
Asphalt concrete for base course				
2, T = 25°C	1.23	0.98	80	70 [11]

The resistance to Frost and water action was obtained on the level of 75-80 %, regardless of the used conditioning procedure. The (1) procedure with test in 5 °C was more restrictive than (3) procedure with the test in 25 °C despite the same conditioning protocol. What is interesting, procedure dedicated to asphalt mixtures, in which there is one cycle of freezing in -18 °C for 16 hours does not reduce the resistance. It could suggest that in the case of cold recycled mixtures more destructive is water action.

3.3 Fracture properties

Test results are presented in Table 3. Obtained results for the cold recycled mixture for binder course are similar to those for cold recycled mixtures for base courses, but much worse than those obtained for hot asphalt mixtures. The K_{IC} intensity factor is around 5 times lower, while the J integral is around 10 times lower than those obtained for hot asphalt mixtures. It suggest that cold recycled mixtures with lower amount of bitumen would provide higher susceptibility to cracking in comparison to typical asphalt concretes.

Table 3 SCB test results

Mixture	K_{Ic} [N/mm$^{3/2}$]	J_c [kJ/m^2]
CRM 0/16 C3E7	4.6	0.20
CRM 0/31 C2E6	4.7	0.26
CRM 0/31 C4E6	8.1	0.22
AC 16 W 35/50	28.0	1.64
AC 22 P 35/50	21.8	2.10

4 Conclusions

Conducted laboratory test proved that cold recycled mixtures presents quite high and sufficient resistance to environmental factors, and the decrease of mechanical properties due to conditioning are on acceptable level.
On the other hand, the conducted laboratory test confirmed quite high susceptibility of the pavement structure with cold recycled mixtures to reflective cracking. Placing cold recycled mixtures in binder course will results in numerous transverse cracks of the surface of the wearing course.
Using cold recycled mixtures is the future of reconstruction of pavements, due to its environmental friendly character, but it still needs a lot of improvements. Using only one thin asphalt concrete will results in high amount of cracks due to low resistance of the cold recycled mixtures. The cracking properties are the area which requires further works. The possible direction of the research are works on dedicated modificatory for bituminous emulsion or using additional materials, such as fibres.
Additionally the obtained results should be confirmed on the field sections, as real life conditions often are very different from those modelled in the laboratory.

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