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Polish experience with cold in-place recycling

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Abstract. Deep cold in-place recycling using cement and asphalt emulsion has been used for reconstruction of existing roads since the beginning of the 1990s. This paper describes the first Polish requirements for mineral-cement-emulsion mixtures. As requirements stated for the strength of the mineral-cement-emulsion mixtures were quite high, most of the mixtures were designed using high amount of cement and aggregate added for the improvement of gradation. The paper also presents selected results of the visual assessment of existing pavements with bases made of mineral-cement-emulsion mixtures. The mixtures used in bases were designed according to the first Polish requirements. On all of the sections numerous reflective transverse cracks were observed. Most of them resulted from very high requirements stated for the strength. Last part of the paper describes the changes which were introduced to the Polish requirements on the basis of conducted field investigations and other past experiences of using mineral-cement-emulsion mixtures in Polish climatic conditions. Newly developed instruction liberalized the requirements stated for base materials and significantly reduced the amount of cement.

1. Introduction

In the 1990s the road system in Poland was underinvested and nearing the limits of its designed fatigue life. The political changes brought a rapid increase in heavy traffic, which resulted in significant degradation of the basic road system. Soon the roads rutted and showed multiple fatigue cracks. The road administration was in need of a technology that would allow for a quick and relatively cost-effective rehabilitation of the deteriorated roads.

One of the solutions that were put into practice in Poland was to use deep cold in-place recycling to mill the distressed pavement into a base made of mineral-cement-emulsion mixture (for the sake of convenience from now on referred to as an „MCE mixture", which is a very popular term in Poland). In order to facilitate the widespread use of the mineral-cement-emulsion mixtures the first Polish requirements [1] were introduced in 1997. They were soon revised, and it was the 1999 version [2] that was widely used and served as a basis for reconstruction of several thousand kilometers of roads in Poland.

This paper describes the Polish experience with the introduction of deep cold in-place recycling as well as the changes that were introduced after the observations from the first years of use of the MCE mixes in Poland were gathered.

2. The Polish requirements from 1999

The Polish requirements [2] assumed the preparation of MCE mixes using reclaimed pavement materials of the following types: mineral-bitumen, mineral-tar, mineral-cement, or only aggregate from existing pavements. The aggregate mix found in materials used for MCE mixes was required to be continuously graded, reaching 31.5 mm or 63 mm particle size, and lie within the range of good grading defined by the limiting curves. Crushed aggregate was added in order to improve the gradation. Asphalt emulsion and cement were used as binding agents. The mentioned materials were widely used in MCE mixes. The recommended cement content was within the range from 1.5% to 4% if an asphalt reclaimed material was used and from 1.5% to 7% in case of tar-asphalt or tar reclaimed material. The recommended asphalt emulsion content was within the range from 3% to 5,5%.

The primary requirements set in the Polish guidelines [2] were as follows:

- Marshall stability at the temperature of +60ºC:
  - for traffic categories KR3 through KR6 (medium and heavy traffic) 8.0 – 20.0 kN
  - for traffic categories KR1 and KR2 (low traffic) 4.0 – 20.0 kN
- Marshall flow at the temperature of +60ºC:
  - for all traffic categories: 1.0 – 3.5 mm
- Air voids for all traffic categories:
  - for specimens compacted with a Marshall hammer, 2 x 75 impacts, in a perforated compaction mold, cured for 28 days at room temperature: 9.0 – 16.0%
  - for specimens pressed with a hydraulic press, constant force of 100 kN for 5 minutes, cured for 7 days at room temperature: 5.0 – 12.0%

Those requirements were meant to facilitate the design of MCE mixes without reference to uncommon test methods. The assessment guidelines for MCE mixes were compatible with capabilities of a typical road laboratory at the time.

3. The need to introduce changes to the requirements for MCE mixes

After several years of use of MCE mixes it turned out that pavements with bases of this type were prone to transverse cracking. Assessment of chosen sections of roads reconstructed with the use of MCE bases showed that in most cases the transverse cracks appeared in quantity of several cracks per kilometer. They were not very numerous, but their number was increasing with time. Observations showed as well that the pavements were generally even, without major distress, with sporadic edge cracks. Fatigue cracking was observed after 5 to 10 years. Typical cracks can be seen in Figures 1, while a specimen cored out at the crack is shown in Figure 2.

Assessment of various sections allowed for defining the problem, which was the occurrence of transverse cracks in roads with bases made of mineral-cement-emulsion mixtures. Information about the composition of the built-in MCE mixtures was obtained in order to establish the probable cause of the problem. The information was gathered both from the road administration and from contractors. In total, mix compositions were obtained for 56 road sections built using this technique. The information served as the basis for detailed analysis of the mineral-cement-emulsion mix formulas used. The quantity of every component in the mixtures was analyzed.

It was found out that among the 56 road sections built using cold in-place recycling:

- 20 sections showed cement content in the mix within the range of 2.5 – 3.9%,
- 24 sections showed cement content in the mix equal to 4%, that is the maximum value according to the technical requirements [2] for MCE mixes using asphalt reclaimed material,
- 6 sections showed cement content in the mix within the range of 5.0 – 5.8%,
- 6 sections showed cement content in the mix equal to 7%, that is the maximum value according to [2] for MCE mixes using tar reclaimed material.

The above set of data shows that there is a tendency to use relatively high amounts of cement. Often the cement content is comparable with the one found in cement stabilization, cement bound mixtures or lean concrete. It is the main factor that results in construction of rigid bases that are prone to cracking.

Figure 1. Transverse crack in the national road No. 7.

Figure 2. A specimen cored out at the crack in the national road No. 7. The crack propagates through the entire pavement.

Among the 56 road sections built using cold in-place recycling:

- 7 sections had emulsion content in the mix higher than 3%,
- 12 sections had emulsion content in the mix lower than 3%,
- 37 sections had emulsion content in the mix equal to 3%, that is the minimum emulsion content according to the Polish requirements [2].

The above comparison shows that the MCE mix bases constructed in Poland contain too little asphalt emulsion, and the strength requirements are met mainly by means of adding high quantities of cement.

It was found out that among the 56 road sections built using cold in-place recycling:

- 13 sections had new aggregate content of up to 30%,
- 34 sections had new aggregate content between 31% and 50%,
- 7 sections had new aggregate content between 51% and 70%,
- 2 sections had new aggregate content above 71 %.

The above breakdown shows that the Polish MCE mix bases contained relatively high quantities of added aggregate – often high-quality crushed aggregate. In most cases its content was higher than 30% of the MCE mix. In 9 cases new aggregate constituted over 50% of the mixtures. It is even hard to consider those as conventional MCE mixtures, since the reclaimed material – and not added aggregate – should have been their primary ingredient.

The analysis of the obtained data about road sections with MCE bases along with the assessment of the state of the pavement on chosen sections showed that:

- Transverse cracks occurred in the majority of sections with MCE mix bases. While not very high in quantity, they showed that there does exist a problem with cracking in pavements with MCE mix bases.
- It is difficult to define the cause of cracking precisely, but all evidence suggested that the observed cracking should be qualified as reflective cracks. Nevertheless, there is a dose of probability that they were caused by low temperature.
- The excessive content of cement in the MCE mixtures should be noted as the probable cause of the distress. The content of cement used in the MCE mixes was not far from the content associated with typical cement bound materials.
- The content of asphalt emulsion used in the MCE mixtures was very low and often does not exceed 3%.
- The MCE mixes contained high quantities of added aggregate, which in many cases disqualifies them in terms of economic viability.

The practical application of the requirements deviated from the basic idea of the mineral-cement-emulsion mixtures, which were originally meant as a flexible course constructed with the highest possible quantity of the material reclaimed from the existing structure. In search for the possible cause, it was found out that the guidelines [2] set relatively high strength requirements, which in practice translated into the use of high quantities of cement as well as new aggregate with good parameters. Emulsion was often added only in order to enable the product to pass as a mineral-cement-emulsion mixture. Such state of affairs forced the road administration to verify the requirements for MCE mixtures.

4. International experience

The first step in the verification of the requirements [2] was an extensive study on design and placement of MCE mixtures worldwide. Information on various countries was gathered, including Germany, England, America, Norway and Sweden. The literature study [3–14] allowed for formulation of the following conclusions:

- The MCE mix design is performed in various ways. Differences occur on every stage of the design procedure, including selection of materials as well as assessment of the produced mixture.
- The choice of aggregate mix is most frequently based on a range of good gradation defined by limiting curves. The space between them is wide and defined in a manner that ensures proper compaction of the mix.
- Minimalization of cement content in MCE mixtures is advised. Requirements in many countries limit the cement content to 1–2%. Where higher cement content is acceptable, the requirements state that the MCE mix should be designed in such a way that the bituminous binding dominates over the hydraulic binding.
- The basic parameter used for MCE mix assessment is the indirect tensile strength. Sometimes the stiffness of the mix is tested as well.
- Moisture susceptibility is tested very often. This parameter is defined on the basis of decrease in strength of specimens subjected to conditioning cycles in comparison with reference specimens. It is particularly significant in countries with high levels of soil moisture and frost.

The comparison between requirements in Poland [2] and in other countries implied the following fields where change was desirable:

- For the gradation of the mineral-cement mix, the Polish guidelines gave limiting curves that defined a narrower range than in most countries.
- An important element that the Polish guidelines were lacking was the assessment of moisture susceptibility of the MCE mixtures.
- In Poland the assessment of mechanical properties of the mix was based primarily on Marshall stability and flow tested at the temperature of +60°C. Tests performed at this temperature did not reflect the real conditions under which the built-in MCE mix functioned. Possibility of relinquishing the Marshall tests needed be taken into consideration. A different criterion – one that was used worldwide – was to be considered instead, that is the indirect tensile strength.
- The Polish guidelines did not take into account the actual stiffness of the produced mixture, which led to placement of mixtures that were too stiff.

5. New requirements for mineral-asphalt mixtures

The past experience with MCE mixes implied that there was a need to revise the requirements considering their production and placement. The literature study served as a source of information on requirements in other countries. Assessment of the practice in Poland showed the areas that needed change. In 2013 the new instruction for the design and placement of MCE mixes [16] was published, encompassing the in-place mixing technique as well as mixing in a stationary plant. The new requirements took into account:

- experience in terms of design, production and placement from various countries,
- widespread use of the material requirements based on the European standards,
- standardized test methods based on the European standards,
- Polish experience from the past practice with MCE mixtures as well as its implications.

The preface to the new requirements includes, among others, the following statements:

- The nature of an MCE base is dual. Depending on the combination of binding agents and the resulting stiffness, MCE mixtures can be divided into two types:
- mixture with dominating bituminous binding – flexible base,
- mixture with dominating hydraulic binding – rigid base.
- Through selection of type and quantity of the binding agents it is possible to achieve different MCE mixtures, whose performance is similar to hydraulically bound bearing courses or to asphalt bearing courses.
- When designing an MCE mixture, one should aim at achieving a dominating bituminous binding in order to minimalize the risk of reflective cracking.
- The mineral-cement-emulsion mixtures designed in accordance with these rules can be freely used in reconstruction and construction of roads subjected to traffic categories from KR1 through KR4 and are compatible with the rules defined in the Polish catalog of typical pavements as well as in the Polish catalog of pavement reinforcement rehabilitation and repair.

In terms of properties of the materials used for MCE mixtures the following requirements were set:

- The reclaimed material is classified as either mineral-bituminous (i.e. mineral-asphalt, mineral-tar or mixed), mineral-cement or mineral. The reclaimed material cannot contain foreign or organic contaminants. It is necessary to determine the type of binder used in it as well as its ratio of bound vs. unbound material.

- Any new aggregate added to the mineral-cement-emulsion mix should be compliant with the PN-EN 13242:2013 standard.
- Asphalt emulsion of the C60B5R type should meet the requirements of the PN-EN 13808 standard.
- Portland cement of type CEM I or multi-ingredient Portland cement of type CEM II, classes 32.5 and 42.5, should be compliant with the PN-EN 197-1 standard.
- Water should meet the requirements stated in the PN-EN-1008 standard.

Even if the material properties meet the above requirements, it may happen that the produced mix does not achieve the required parameters. The design procedure of the MCE mix should be repeated then with different ingredients or modified ingredient proportions.

The mix design process was divided into several successive steps. They were ordered as follows:

- Design of the mineral mix, which may contain reclaimed material plus new aggregate or only reclaimed material. The gradation of the mix should be continuous. Maximum particle size should not exceed 31.5 mm, but there is a 15% tolerance margin for particles retained on the first sieve.
- Choice of the binding agents. Combination of the binding agents should be determined in accordance with the following general rule:
  - asphalt emulsion: from 2% to 6% (mass content),
  - cement: from 1% do 4% (mass content).

The desired combination of binding agents is the one where the cement content is as low as possible, which minimalizes the risk of reflective cracking.

- Proper design of the MCE mixture should be carried out according to the following procedure:

  - Initial determination of the materials planned for use in the mineral mix.
  - Choice of the binding agents.
  - Determination of the optimum liquid content.
  - Determination of the quantity of water that should be added in order to achieve the optimum liquid content.
  - Forming of mineral-cement-emulsion mix samples for determination of physical and mechanical properties of the mix.
  - Storage of the samples during the setting process.
  - Performance of the tests necessary for determination of physical and mechanical properties.
  - Determination of the MCE mix formula.

Each of the above steps is described precisely in the requirements. The designed MCE mix should meet the requirements given in Table 1.

- The requirements give relatively precise rules for placement and acceptance of the MCE mix courses. An MCE base should be built in such a manner that guarantees its homogeneity and compaction without any visible weak, damaged or non-homogeneous areas. The requirements for the compacted MCE course are given in Table 2.

The above requirements were introduced in practice in 2014. After a transition period, the majority of new projects are currently realized based on the new requirements.

Table 1. Requirements for the designed MCE mixture

Property:	Required values:	
	Traffic KR1 and KR2 (low traffic)	Traffic KR3 and KR4 (medium traffic)
Content of air voids	8% to 18% (vol.) max.14% (vol.)[1)]	8% to 15% (vol.) max.12% (vol.)[1)]
Indirect tensile strength, T = + 5°C, after 7 days, [MPa]	0.40–0.90	0.50–1.00
Indirect tensile strength, T = +5°C, after 28 days, [MPa]	0.60–1.40	0.70–1.60
IT-CY stiffness modulus, T = +5°C, after 28 days, [MPa]	1500–4000	2000–5000
Remaining indirect tensile strength after storage in water, no less than [%]	70	80

[1)]For reclaimed materials that include tar.

Table 2: Requirements for the compacted MCE course

Parameter	requirement	
	Traffic KR1 and KR2 (low traffic)	Traffic KR3 and KR4 (medium traffic)
Relative compaction	≥ 98%	≥ 98%
Air voids	≤ 15% vol.	≤ 12% vol.
Base course bearing capacity:		
• Secondary deformation modulus E_2	$E_2 \geq 140$ MN/m^2	$E_2 \geq 180$ MN/m^2
• Dynamic deformation modulus E_{vd}	$E_{vd} \geq 70$ MN/m^2	$E_{vd} \geq 90$ MN/m^2

6. Summary

The Polish experience showed that improperly defined requirements for MCE mixtures may lead to production of an overly stiff mix, resulting in transverse cracking of the pavement. The change to the requirements was meant to introduce a tendency to design MCE mixtures that are less rigid. The first cases of their usage are promising.

When producing an MCE base it is necessary to make it as flexible as possible in order to minimalize the risk of reflective cracking which may appear in such pavements.

For the last few years interest in deep cold recycling has been increasing in Poland. Apart from the fact that the road administration used the technique more often, especially on local roads, the scientists have been carrying out research on a greater scale [17, 18]. The research is in accord with the international tendency to use and test mixtures that include materials recovered from existing pavements [18, 19, 20].

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