Bituminous emulsions

# New concept of durable flexible sub-base with use of deep cold recycling mixtures

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Abstract

Nowadays, recycling of asphalt pavements is a necessity due to decreasing natural resources and implementation of the principles of sustainable development. Bituminous materials as one of the oldest construction materials are ecological due to the possibility of their total recycling. This article presents the evolution of the Polish standards for deep cold recycling technology, assesses the functional aspects of BSMs and analyses the applicability of the new technology for sub-base layer construction. The technology of deep cold recycling using cement and asphalt emulsions allows to quickly reconstruct road structure on site. The addition of cement allows to obtain increased bearing capacity of the road structure immediately after construction, but too large amount of cement causes over-stiffening and cracking of road pavement layers. The paper presents research results concerning mechanical properties of Mineral-Cement-Emulsion with various amounts of active filler and bituminous binder as well as properties of binders stabilised from experimental bitumen emulsions. The research results allow to state that the influence of bitumen emulsion content and type should be investigated on mixes containing smaller amounts of cement where the dominant role of the active filler in the MCE mix is reduced.

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## 1. INTRODUCTION

Nowadays, as a strong emphasis is put on maintaining and reconstruction of the existing road network rather than extending it, cold recycling technology is generating considerable interest in terms of sustainable rehabilitation of pavements. Being both ecologically and economically advantageous, it contributes to a decrease in the use of raw materials by replacing them with a significant amount of recycled materials such as Reclaimed Asphalt Pavement (RAP), helps to cut down on costs and energy consumption compared to Hot Mix Asphalt (HMA) production, as well as allows the reduction of greenhouse gas emissions since no heating processes during manufacturing and paving are required.

Thanks to the wide availability of RAP, cold recycling technology is becoming more and more commonly applied in the construction of the base and sub-base courses. Cement-Bitumen-Emulsion-Mixtures (CBEM), also called Mineral-Cement-Emulsion (MCE) mixtures, are considered as a standard cold recycling solution that is gaining popularity in terms of pavement rehabilitation in Poland. For the past two decades, high tensile strength and high stiffness modulus resulting from high cement content have been considered as critical properties of the MCE materials. However, it has been found that the high amount of cement used in mixtures (exceeding 2,5%), caused over stiffening of the material and resulted in transverse reflective cracking of pavements [1].

In order to prospectively eliminate the rigidity of the MCE mixes, the current trend in design of cold recycling mixtures is towards reducing the amount of cement used and obtaining the desired durability by improved flexibility of the material. This goal can be achieved by utilising Bitumen Stabilised Materials (BSMs) that are less stiff and less prone to shrinkage cracking. The new concept of cold recycling mixtures called MCE+ is also accomplished by using innovative types of cationic bitumen emulsions.

This article presents the evolution of the Polish standards for cold recycling mixtures, assesses the functional aspects of BSMs and analyses the applicability of the new technology for sub-base layer construction. The research results concerning mechanical properties of Mineral-Cement-Emulsion with various amounts of active filler and bituminous binder as well as properties of binders stabilised from new bitumen emulsions are shown here.

## 2. OBJECTIVES

The overall objective of the MCE+ research programme presented in this paper was to develop a new concept of durable and flexible BSM mixtures for sub-base courses of Polish roads. Bitumen Stabilised Materials characterised by improved shear properties (cohesion) and a reduced amount of cement were contrasted with traditionally used MCE mixtures.

The potential benefits of the use of innovative types of bitumen emulsions in BSMs were evaluated based on the results obtained from tests conducted on stabilised binders. The effect of the utilisation of various cement and bitumen emulsion amounts on the stiffness and tensile strength of the material were investigated by performing tests on laboratory-compacted MCE reference and new BSM mixes.

## 3. EVALUATION OF THE APPLICABILITY OF BITUMEN STABILISED MATERIALS IN POLAND

### 3.1. Evolution of Polish standards for cold recycling mixes

During the 1990s a vast number of Polish roads were suffering from various signs of degradation, such as rutting, cracking or local material loss that caused a significant deterioration in the pavement quality. In order to rebuild safe traffic infrastructure, an efficient and economical pavement rehabilitation technology needed to be applied. In 1997, the first Polish requirements for cold recycling mixtures called Mineral-Cement-Emulsion (MCE) mixes were introduced [2] followed by the revised version in 1999 [3], which became a basic instruction for the rehabilitation of distressed pavements. These mixes consisted of RAP mixed with virgin aggregates, water and stabilising agents in the form of cement and slow-setting cationic bitumen emulsion to ensure proper flexibility of the material.

However, as reported by Dolzycki & Jaskula [1], after the field validation of the state of reconstructed pavements built with MCE bases that were designed following the revised instructions [3], a considerable number of transverse cracks were observed. The main reason for the presence of the reflective cracks appeared to be the shrinkage and cracking of overly stiffened MCE layers constructed with an excessive amount of cement (exceeding 2,5%) in order to meet the high Marshall stability requirements.

Considering the original assumption of MCE being a flexible material containing a significant amount of RAP, the national requirements were again revised and, in 2014, the new instruction for the MCE mixes design and placement was introduced [4]. Compared to the previous guideline which aimed to design a durable material with high load-bearing capacity classified by Marshall stability and flow, the current requirements take into account indirect tensile strength, stiffness modulus and moisture susceptibility of the material (Table 1).

**Table 1. Evolution of Polish standards for deep cold recycling mixtures [3, 4]**

| | | |
|---|---|---|
| **1. Technical Requirements for the Construction of Base Course Layers with Mineral-Cement-Emulsion Mixes (1999) [3]** | | |
| **Total binder content** | For mixes with $D_{max}$ = 12 mm and 31,5 mm | ≤ 6% by mixture mass |
| | For mixes with $D_{max}$ = 63 mm | ≤ 5,5% by mixture mass |
| **Marshall stability at 60°C** | - for medium and heavy traffic | 8 – 20 kN |
| | - for light traffic | 4 – 20 kN |
| **Marshall flow at 60°C** | - for all traffic | 1,0 – 3,5 mm |
| **Air voids** | - for all traffic<br>Specimens compaction method:<br>- Marshall hammer 2x75 blows<br>- hydraulic press, 100kN constant force | <br><br>9 – 16 %<br>5 – 12 % |
| **2. Guidelines for Design and Paving of Mineral-Cement-Emulsion Mixes (2014) [4] – current standard** | | |
| **Indirect tensile strength ITS, 5°C** | - for light traffic | 0,4 – 0,9 MPa (7 days)<br>0,6 – 1,4 (28 days) |
| | - for medium traffic | 0,5 – 1,0 MPa (7 days)<br>0,7 – 1,6 MPa (28 days) |
| **Stiffness modulus ITSM, 5°C (28 days)** | - for light traffic<br>- for medium traffic | 1500 – 4000 MPa<br>2000 – 5000 MPa |
| **Tensile strength retained (TSR), after storage in water, no less than** | - for light traffic<br>- for medium traffic | 70 %<br>80 % |
| **Air voids** | - for light traffic<br>- for medium traffic | 8 – 18 %<br>8 – 15 % |

*Traffic categories in Poland: light traffic - categories KR1-KR2, medium traffic - categories KR3-KR4, heavy traffic - categories KR5-KR7*

However, as the range of the allowable amount of cement in new revised MCE mixes remains at the level of 1-4%, the possibility of the occurrence of reflective cracking of pavements still exists. Mineral-Cement-Emulsion mixes prepared with a relatively high amount of cement may behave similarly to Cement Treated Materials (CTM) that are prone to shrinkage manifesting in block cracking of the sub-base layer, additionally intensified by repetitive traffic load. Recent studies [5] highlight that it is vital for the balance between the strength and physical properties such as drying shrinkage, erodibility, capillary rise and absorption of CTM mixes to be taken into account during the design process. In the case of Cement-Bitumen-Treated-Mixtures (CBTMs), as stated by Kavussi & Modarres [6], the addition of cement (up to 2,5%) was beneficial in case of stiffness, shear strength, resistance to permanent deformation and moisture sensitivity of the mixes. However, this relatively high cement content may reduce the ability of the material to sustain repetitive loading.

Since the durability and flexibility of the material are of key importance, the application of Bitumen Stabilised Materials (BSMs) with a reduced amount of active fillers and improved shear properties thanks to the relatively high residual binder content seems to be a promising solution.

### 3.2. Properties of Bitumen Stabilised Materials (BSMs)

Cold recycling mixes consisting of: RAP, virgin aggregates, bituminous binder (bitumen emulsion or foamed bitumen), active filler (cement) and water in which the residual bitumen/cement ratio is greater than one and with the cement content lower than 1% are called Bitumen Stabilised Materials (BSMs) [7].

Recently, much more information on BSMs' mechanical behaviour has become available thanks to the worldwide research [8-10]. BSMs are considered to be uniquely different from all other materials used to construct road pavements. It is mainly because of their non-continuously bound nature - the bitumen in a BSM is selectively dispersed among the fine particles of aggregate and active filler creating local bonds between the coarse aggregates' skeleton [7]. Considering two main types of Bitumen Stabilised Materials - BSMs with bitumen emulsion and BSMs with foamed bitumen, the second one has been investigated in Poland by Iwanski and Chomicz-Kowalska [11-13]. Taking Polish traffic, weather conditions and availability of recycled materials into account, they emphasise the role of the suitable bitumen type selection in case of providing high physical - mechanical parameters of the pavement, as well as careful aggregate blend composition (inhomogeneous or tar-contaminated RAP) [1,12]. The maximal allowable amount of Portland cement in cold recycling mixes was also examined and suggestions considering introduction of the frost resistance criterion for the BSMs were presented [12].

According to the leading BSMs' behavioural phases hypothesis presented by Ebels [14], the service life of these materials consists of 2 phases:

- I - curing phase with an increase in initial stiffness resulting from moisture reduction and densification of the BSM layer. In this phase BSMs are considered to behave like unbound granular materials and characterised by stress dependency;
- II - stiffness reduction phase when BSMs demonstrate a quasi-viscoelastic behaviour with temperature, time and load frequency dependence characteristic for Hot Mix Asphalt (HMA).

As reported by Perez, Medina, de Val [10] the properties connected to the "unbound granular material" character of BSMs include:

- Cohesion (c) and the angle of internal friction measured in static triaxial tests that determine the resistance to shear stress and, as a result, the resistance to permanent deformation.
- Resilient modulus (Mr) obtained in dynamic triaxial tests.

The viscoelastic response of BSM mixes can be evaluated by creep compliance, ITFT fatigue resistance or ITSM stiffness modulus tests. The two main failure mechanisms of BSMs are considered to be permanent deformation and moisture susceptibility [15].

As the properties of Bitumen Stabilised Materials result from the interaction of two binding agents - bitumen emulsion/foamed bitumen and the active filler (cement), the balance between flexibility and rigidity must be sustained. The role of the active filler in BSMs is mostly related to the acceleration of the bitumen emulsion breaking process. Nevertheless, it should be highlighted that even small amounts of cement (1% by mass) can enhance the mechanical properties of the mixes as well as decrease their moisture sensitivity, thanks to the presence of cement hydration products, increasing the coalescence of bitumen droplets as well as increasing the binder viscosity [16].

## 4. RESEARCH PROGRAMME

The MCE+ research programme consisted of 2 parts:

- part I: evaluation of the properties of binders stabilised from bitumen emulsions,
- part II: determination of the impact of the amount or type of binding agents (cement and bitumen emulsion) used in MCE mixtures on the mechanical properties of the material - statistical analysis.

### 4.1. Materials and experimental design

In the first part of the research, three different types of slow setting cationic bitumen emulsions were used to conduct tests:

- T1: reference bitumen emulsion C60B10 ZM/R (according to PN-EN 13808) containing bitumen with penetration grade of 70/100 (typically used for Polish MCE mixtures),
- T2: experimental bitumen emulsion produced on the base of 70/100 penetration grade bitumen with the addition of polymer latex dispersion,
- T3: experimental bitumen emulsion produced on the base of 50/70 penetration grade bitumen.

In the second stage of the research, MCE mixtures with RAP (Reclaimed Asphalt Pavement) were designed. RAP derived from the milling of bituminous layers of the provincial road. The average binder content in RAP was 5% by mass. In order to meet the grading criteria presented in national standards, basalt aggregate 0-31,5 mm was added to the aggregate mixture. For testing purposes, particles of a size larger than 22,4 mm were discarded. Bitumen emulsions used in the first part of the research were also used here. Portland-slag cement CEM II/B-S 32,5R (according to EN 197-1) was included as an active filler in the mix design.

To examine the mechanical properties of MCE, three different amounts of cement (1%, 2% and 3% by mixture mass) and bitumen emulsion (3%, 4,5% and 6% of mixture mass), as well as three different types of the commercially available bituminous binding agents were adopted in the mixture design process. The variety of binding agent contents were introduced to compare the mechanical properties of traditionally produced mixes with a high amount of cement with mixes with reduced content of active filler to be close to BSM technology.

The aggregate blend for MCE mixes was prepared with 50% RAP and 50% of basalt aggregate in order to meet the grading criteria for the medium traffic loading categories (KR3-KR4) according to Polish requirements [4]. Particle size distribution of the designed MCE mixes compared to the target grading is shown in Figure 1.

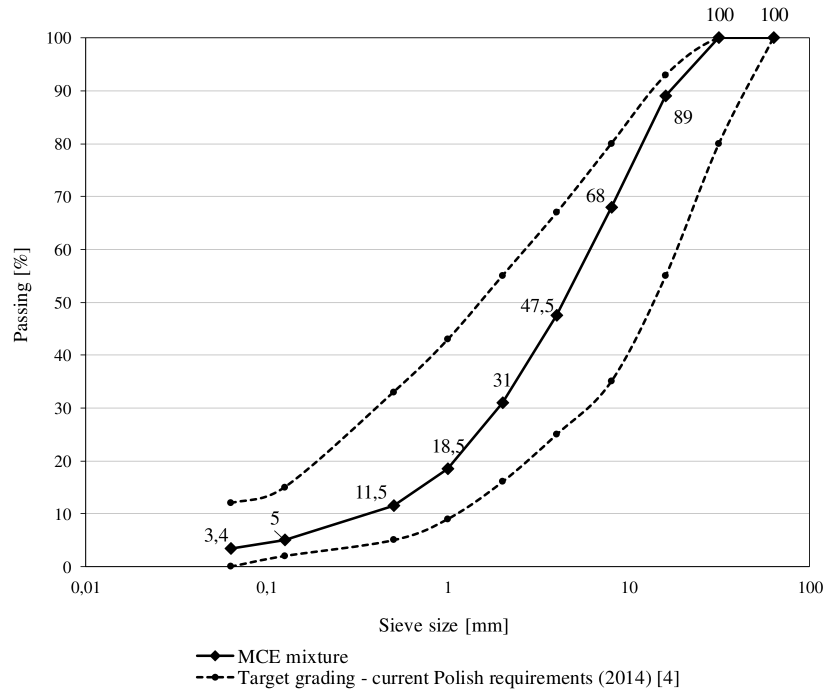



**Figure 1: Gradation curve of the MCE mixture**

The optimum fluid content (OFC) was determined as 5,9% using the Proctor method defined by PN-EN 13286-2. The amount of the water to be added in each of the mixes was calculated in accordance with national instructions [4].

The process of the statistical selection of the MCE mixtures to be tested in the second part of the research is presented in Figure 2. Considering the chosen number of independent variables, the application of $3^{k-p}$ fractional factorial design using Design of Experiment (DOE) module in the *Statistica* software allowed to reduce the number of required tests from 27 ($3^3$ full factorial experiment design) to 9 ($3^{3-1}$ fractional factorial experiment design). The linear model with the analysis of the main effects (cement and bitumen emulsion content, bitumen emulsion type) was chosen to fit to the experimental results.

**Figure 2. Statistical selection of the MCE mixture compositions**

| Matrix of parameters ($3^3$ full factorial experiment design) | | | |
|---|---|---|---|
| Mixture No. | Cement content [%] | Bitumen emulsion content [%] | Bitumen emulsion type |
| 1 | 1,0 | 3,0 | T1 |
| 2 | 2,0 | 4,5 | T2 |
| 3 | 3,0 | 6,0 | T3 |
| 4 | 1,0 | 4,5 | T1 |
| 5 | 1,0 | 6,0 | T1 |
| 6 | 2,0 | 3,0 | T1 |
| ... | ... | ... | ... |
| 25 | 1,0 | 3,0 | T3 |
| 26 | 2,0 | 4,5 | T1 |
| 27 | 3,0 | 4,5 | T2 |

**fractional selection**

| Matrix of parameters ($3^{3-1}$ 3-level fractional factorial experiment design) | | | |
|---|---|---|---|
| Mixture No. | Cement content [%] | Bitumen emulsion content [%] | Bitumen emulsion type |
| 1 | 1,0 | 3,0 | T3 |
| 2 | 2,0 | 3,0 | T2 |
| 3 | 3,0 | 3,0 | T1 |
| 4 | 1,0 | 4,5 | T2 |
| 5 | 2,0 | 4,5 | T1 |
| 6 | 3,0 | 4,5 | T3 |
| 7 | 1,0 | 6,0 | T1 |
| 8 | 2,0 | 6,0 | T3 |
| 9 | 3,0 | 6,0 | T2 |

The compositions of the 9 MCE mixtures selected according to the process presented in Figure 2 are shown in Table 2.

**Table 2. Selected compositions of the MCE mixes**

| Selected mixtures | Bitumen emulsion content [%] | Total binder content [%]* | Bitumen emulsion type | Cement content [%] | Aggregate blend |
|---|---|---|---|---|---|
| C1E3_T3 | 3 | 4,11 | 50/70 | 1 | 50% RAP + 50% basalt aggregate |
| C2E3_T2 | | 4,08 | 70/100 + latex | 2 | |
| C3E3_T1 | | 4,06 | 70/100 | 3 | |
| C1E4,5_T2 | 4,5 | 4,99 | 70/100 + latex | 1 | |
| C2E4,5_T1 | | 4,97 | 70/100 | 2 | |
| C3E4,5_T3 | | 4,94 | 50/70 | 3 | |
| C1E6_T1 | 6 | 5,88 | 70/100 | 1 | |
| C2E6_T3 | | 5,86 | 50/70 | 2 | |
| C3E6_T2 | | 5,83 | 70/100 + latex | 3 | |

* - Total binder content = bitumen emulsion residual binder + binder from RAP

Statistical approach was developed to evaluate an effect size of the independent variables on stiffness moduli or tensile strength, which permitted the researchers to determine whether a statistically significant result is meaningful, i.e. whether a change in the amount of cement/bitumen emulsion or the type of bitumen emulsion has an impact on the mechanical properties of the MCE mixture.

### 4.2. Specimen preparation and testing methods

The tests conducted in the first part of the research aimed to assess basic properties of binders used for their classification according to EN 12591 and EN 14023 as well as to compare the dynamic viscosity of bitumens as a vital property for developing the shear performance of the mixes.

Testing material was prepared following EN 13074-1 and EN 13074-2 procedures. Recovered and stabilised binders (STAB) were subjected to following tests: penetration at 25°C, softening point by R&B method and dynamic viscosity at 90, 110 and 135°C.

The designations of the binders stabilised from bitumen emulsions were created based on the type of bitumen utilised for the production of each of the bitumen emulsions:
- for binder stabilised from T1 bitumen emulsion: 70/100 STAB,
- for binder stabilised from T2 bitumen emulsion: 70/100 + latex STAB,
- for binder stabilised from T3 bitumen emulsion: 50/70 STAB.

In the second part of the research, the MCE mixes were prepared. The constituents of MCE mixtures were manually mixed. The loose mix was compacted into specimens of a height of 63.5 ± 3.5 and a diameter of 101.6 mm using Marshall compactor by applying 75 blows per side. All the specimens were tested after 28 days of curing at ambient temperature (20±5°C) and relative air humidity of 55%.

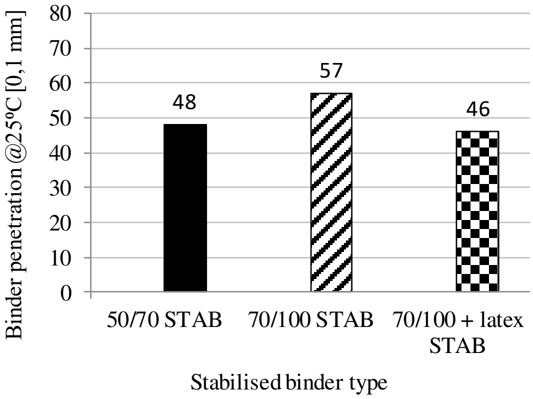
Tensile strength of the MCE mixes was determined according to EN 12697-23 in Indirect Tensile Strength (ITS) tests by applying load at a rate of 50 mm per minute until specimen failure at 25°C. Stiffness modulus tests were performed according to EN 12697-26 (Annex C) standard at 5, 13 and 20°C using an UTM-25 testing apparatus (Fig.3). The cyclic impulsive load, with rise-time of 124 ms, was adjusted to achieve a target horizontal deformation of 5 μm.

**Figure 3: Stiffness modulus IT-CY testing**

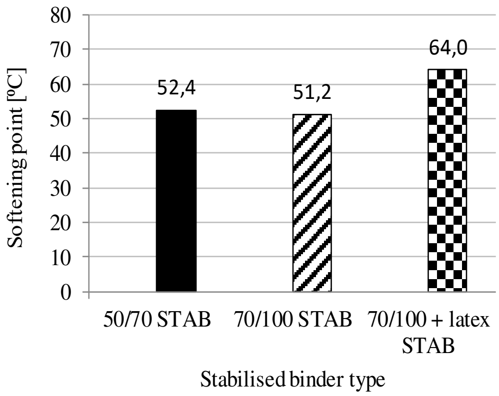
## 5. RESULTS AND DISCUSSION

### 5.1. Properties of binders stabilised from bitumen emulsions

Penetration tests revealed that, for all stabilised binders, the penetration values were below the standard range for paving grade bitumens that were utilised to produce each of the bitumen emulsions (Fig. 4a) which means that the bitumen emulsion production as well as the recovery and stabilising process may influence the properties of the binder. The lowest penetration value was determined for 70/100+latex STAB bitumen. It is hypothesised, that the noticeable increase in the hardness of the 70/100+latex STAB binder resulted from the addition of a latex modifier. It should be also noted that the presence of the elastomer contributed to decreasing the penetration value of the 70/100+ latex STAB binder by 19% compared to the 70/100 STAB binder.




a)




b)

**Figure 4: Test results of binders stabilised from bitumen emulsions: a) penetration at 25°C, b) softening point**

Based on the results of the softening point tests, it can be noticed that low diversity of the softening point values was found for binders stabilised from bitumen emulsions containing paving grade bitumens (50/70 STAB and 70/100 STAB) (Fig. 4b). Considering the high softening point (64°C) of the 70/100 + latex bitumen combined with its low penetration, the enhanced binder's resistance to deformation at high operating temperatures could be predicted. It is anticipated that the penetration and softening point values obtained for this bitumen are the results of the presence of the latex modifier introduced into the emulsion during its production.

The results of the dynamic viscosity tests at 90, 110, 135°C are presented in Figure 5 and Table 3.

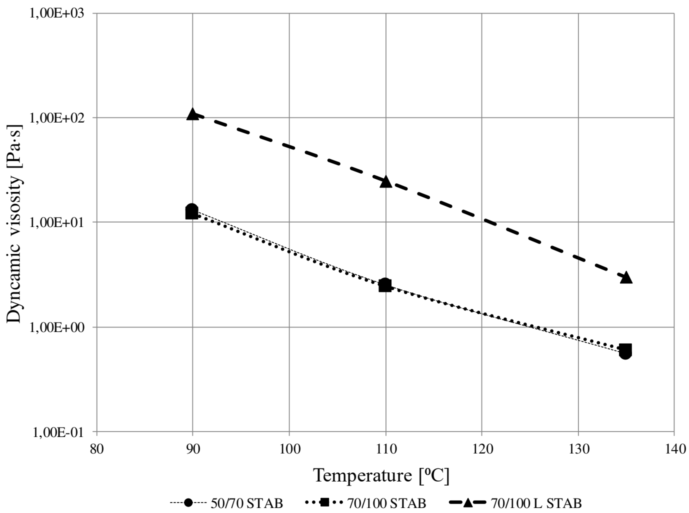



**Figure 5: Dynamic viscosity test results of binders stabilised from bitumen emulsions**

**Table 3. Dynamic viscosity of binders stabilised from bitumen emulsion at 90, 110 and 135°C**

| Binder | Dynamic viscosity [Pa·s] | | |
|---|---|---|---|
| | 90°C | 110°C | 135°C |
| 50/70 STAB | 13,1 | 2,52 | 0,551 |
| 70/100 STAB | 12,1 | 2,44 | 0,598 |
| 70/100 + latex STAB | 109 | 24,9 | 3,00 |

As it was predicted from the penetration and softening point test results, higher dynamic viscosity of 70/100 + latex STAB binder compared to the rest of the tested bitumens was found. Similar values of viscosity in all temperatures were determined for 50/70 STAB and 70/100 STAB binders.

Since the properties of the 70/100 + latex STAB binder visibly diverge from those obtained for the other binders, the performance of BSM mixtures incorporating T2 emulsion was thoroughly investigated.

### 5.2. Indirect Tensile Strength and Stiffness modulus of MCE mixes

The results of Indirect Tensile Strength and stiffness modulus IT-CY tests for MCE+ mixtures are presented in Figures 6-7. Nine types of MCE+ mixtures were selected using the $3^{k-p}$ fractional factorial design of experiment (DOE) as indicated in section 4.1. According to the implemented DOE approach, this number of mixtures is sufficient to successfully determine whether a change in the amount of cement and bitumen emulsion or the type of bitumen emulsion (main effects) has a statistically significant impact on the mechanical properties of the MCE mixtures.

According to expectations, the tensile strength and stiffness modulus of the mixes increased gradually with the increase of the amount of cement applied. Results obtained for the C2E4,5_T1 mix were not expected, as the ITS and stiffness modulus values were higher than those determined for the C3E4,5_T3 mix that contained 3% of cement. However, the reason for this is probably the inhomogeneity of materials used, as the process of specimens preparation and curing was conducted under repeatability conditions.

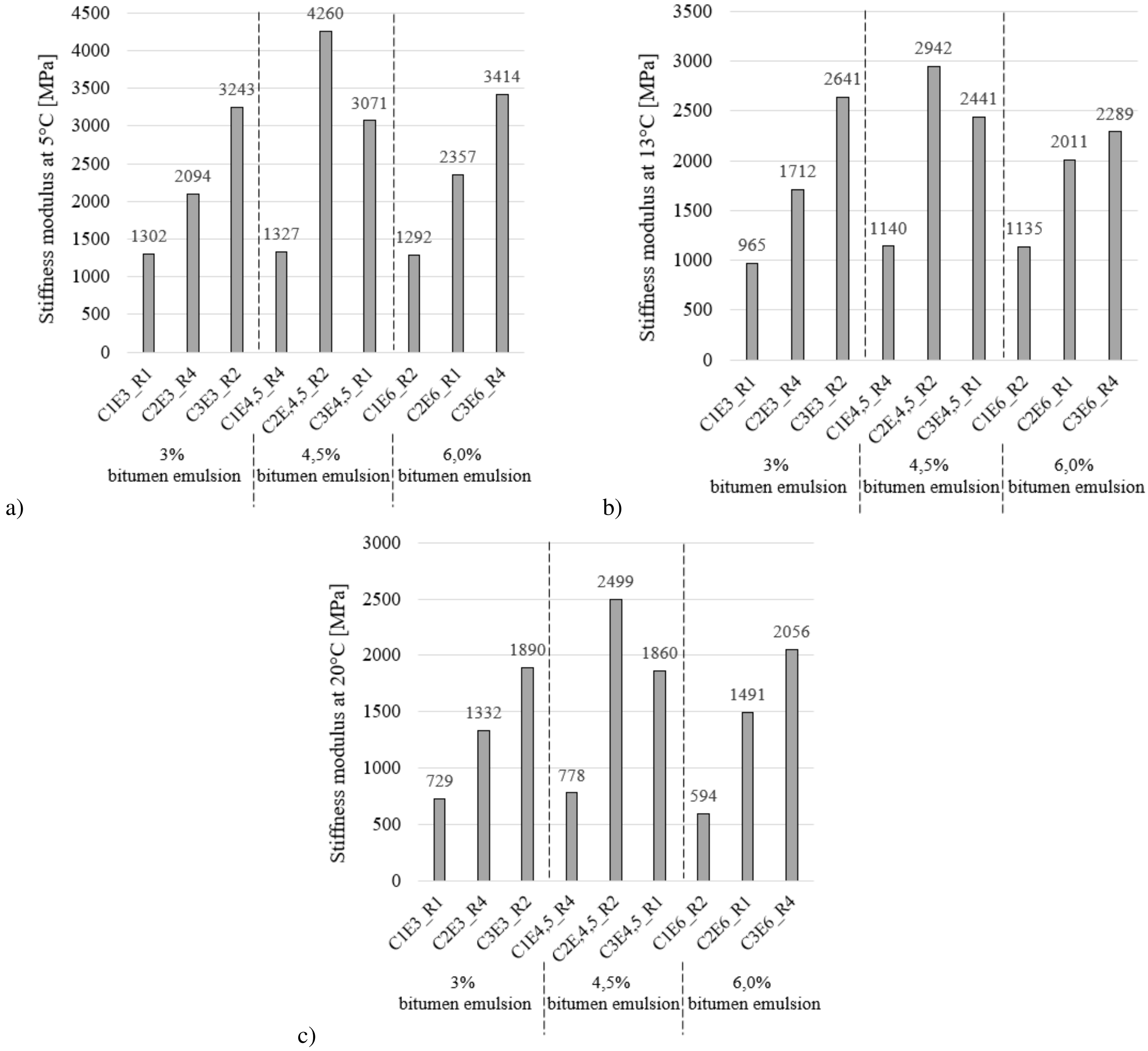



**Figure 6: Stiffness modulus of the MCE mixtures: a) at 5°C, b) at 13°C, c) at 20°C**

As shown in Figure 6 (a-c), in all cases the stiffness modulus IT-CY of the mixes decreased with the increase of the testing temperature. The values of stiffness modulus at 5°C determined for mixes with 2% and 3% cement content meet the requirements presented for traffic loading categories from KR1 to KR4 according to the Polish Catalogue of Typical Flexible and Semi-rigid Pavement Structures [17]. Even though the stiffness obtained for the mixes with a reduced amount of cement (1% by mixture mass) was insufficient in terms of these requirements, the measured values are recognised as correct based on the literature review [6].

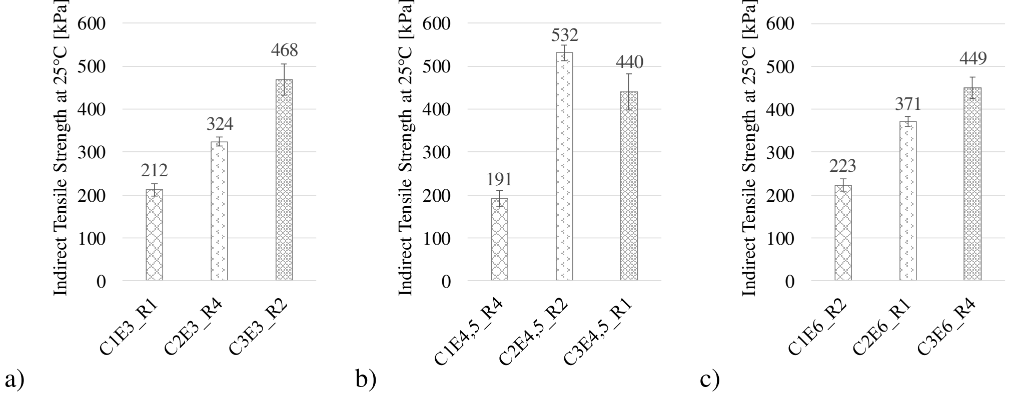



**Figure 7: Indirect Tensile Strength of the MCE mixtures: a) containing 3% bitumen emulsion b) containing 4,5% bitumen emulsion c) containing 4,5% bitumen emulsion**

ITS test results were ordered by the same values of bitumen emulsion content and increasing values of cement content (Fig.7 a-c) Similar values of ITS were observed for mixes with the same amount of cement, regardless of a bitumen emulsion content. The largest standard deviations of ITS values were observed for mixes containing 3% of cement. The statistical analysis results are presented in Figures 8 a-d as standardised pareto charts for each of the dependent variables (IT-CY 5°C, 13°C, 20°C and ITS).

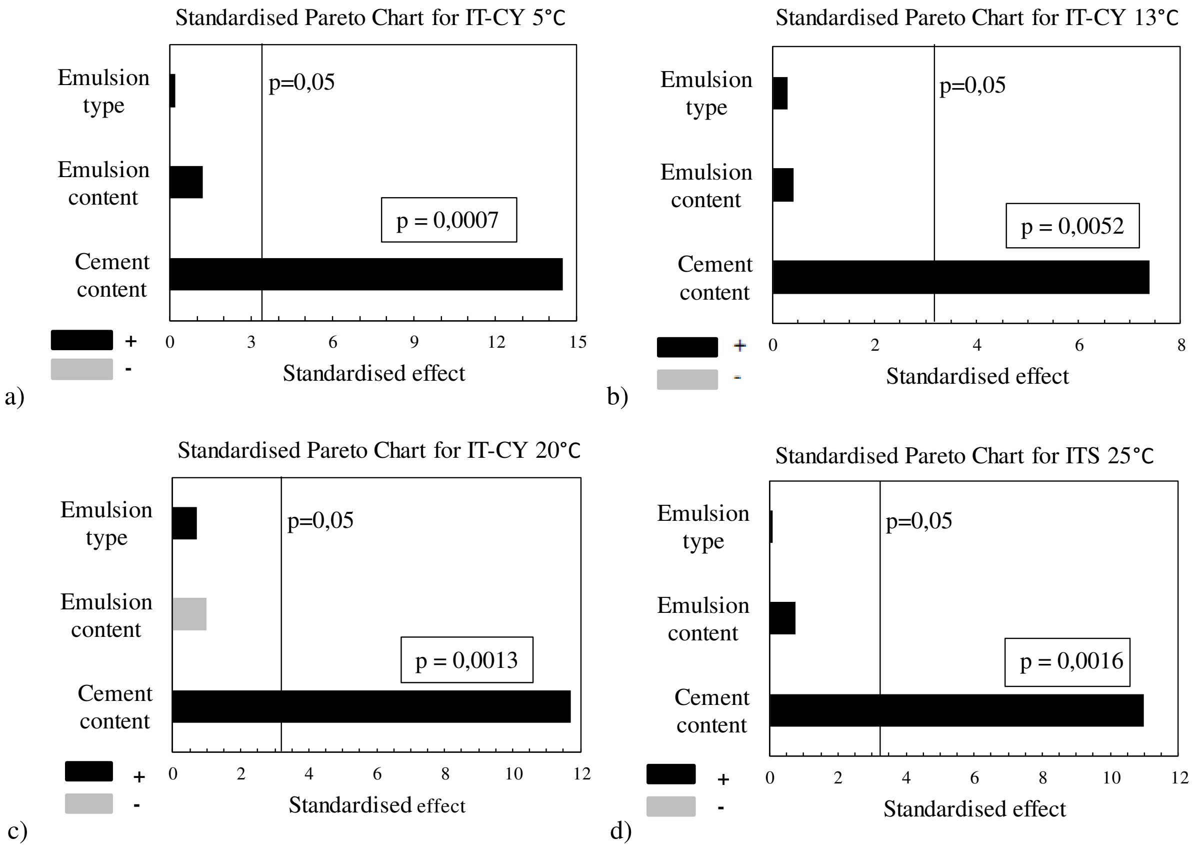



**Figure 8: Pareto charts of standardised effects of the cement and bitumen emulsion contents and bitumen emulsion type on the IT-CY and ITS values**

Statistical analysis has proven that the cement content was the most important factor affecting tensile strength and stiffness modulus at 5°C, 13°C and 20°C of the designed mixes. The research results allow to state that the influence of bitumen emulsion content and type should be investigated on mixes containing smaller amounts of cement where the dominant role of the active filler in the MCE mix is reduced.

## 6. SUMMARY AND CONCLUSIONS

In this paper, the Polish standards for cold recycling mixtures and potential benefits of the use of BSMs in pavement construction were assessed. The research programme consisted of the examination of tensile strength and stiffness modulus of MCE mixes as well as evaluation of properties of binders stabilised from bitumen emulsions. Based on the conducted tests, following conclusions can be drawn:

- In cold recycling mixes containing bitumen emulsion and high amount of cement, the hydraulic bonding is considered to be dominant. The use of materials with dominating bituminous bonding allows to reduce the risk of reflective cracking in pavements.
- Bitumen Stabilised Materials (BSMs), characterised by the combination of mechanical properties of granular (stress-dependent behaviour) and viscoelastic materials (time and temperature-dependent behaviour), can be a suitable solution for sub-base layer construction providing the proper proportion of binding agents applied.
- Cement is the major factor affecting tensile strength and stiffness modulus of the MCE mixes.
- The influence of the amount and type of bitumen emulsions on the properties of the BSM can be fully assessed through the reduction of the cement content (not higher than 1% mixture mass).
- Binders stabilised from bitumen emulsions containing a latex modifier displayed properties that are noticeably different from properties of binders stabilised from conventional bitumen emulsions.

## 7. AKNOWLEDGEMENTS

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