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Limiting the cracking of MCE mixtures used in base layers

Abstract: The subject of the analysis conducted in the article are mineral-cement-emulsion (MCE) mixtures containing reclaimed asphalt pavement (RAP). The mixtures contain innovative road binders based on cement-dusty by-products (UCPP). These binders, used instead of conventional cement, can reduce the stiffness of the resulting conglomerate, which will reduce thermal cracking in the road pavement base layers. UCPP binders can also contribute to the decarbonization of the MCE mixture production process. The conducted research demonstrated a significant effect of UCPP binders on the mechanical properties of recycled MCE mixtures. Crack propagation was analyzed using the SCB and UTST methods. As a result of the research, the binders were selected which most effectively limited cracking and its growth rate. These analyses contribute to a detailed understanding of the effective use problem of MCE mixtures with reclaimed asphalt in road pavement construction.

Keywords: cement-dusty by-products (UCPP), crack propagation, mineral-cement-emulsion mixture, recycling.

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1. INTRODUCTION

1.1. MATERIALS USED IN MCE

The problem of the large amount of waste in today's world is very current. Every effort should be made to reduce the waste generation and recycle as much of what is generated as possible. Recycling, meaning the reuse of degraded materials, is necessary. Recycled materials are used worldwide in various fields, including the road engineering. One example is the United States, where waste is used for example in concrete pavements. Waste materials used in new road pavements include: coal combustion ash, coal combustion bottom ash, municipal solid waste (MSWI) combustion products, glass waste, casting sand, reclaimed concrete aggregate (RCA), and construction and demolition waste (CDW) [1].

Also, due to limited mineral resources, the search for alternative materials for road pavement layers has become important. Recycling and utilization are solutions that deliver measurable environmental and economic benefits.

Road pavements recycling reduces landfill waste from damaged road, reduces the demand for natural mineral resources, and lowers aggregate transportation costs. Materials improving the gradation and binders are used to increase the strength of the layers. Binders include asphalt binders (asphalt emulsion or foamed asphalt). Hydraulic binders include cement binders and innovative binders derived from dusty by-products.

Reusing reclaimed asphalt, after proper preparation and mixing with binders such as asphalt emulsion and cement binder, enables the production of high-quality materials for road pavement layers. A mineral-cement-emulsion (MCE) mixture, characterized by continuous grain size, consists of reclaimed asphalt and mineral aggregate. It is made using cold-mix technology with cement and asphalt emulsion in specific proportions, under optimal moisture conditions [2].

It is used in road pavement base and sub-base layers. Scientific studies in the field of civil engineering have demonstrated that road construction layers containing various types of additives and so-called reclaimed asphalt achieve very good mechanical properties [3].

MCE mixtures containing reclaimed asphalt or reclaimed concrete are intended for both upper and lower base layers and reinforced subgrades [4]. The mechanical properties of mixtures (Cold Asphalt Emulsion Mixtures) containing up to 70% reclaimed asphalt pavement (RAP) meet the requirements for their use in road structures [5]. A 45% reclaimed concrete content allows for optimal grading of the mineral mixture and maximum strength properties [6]. This solution will significantly reduce the number of so-called reflected cracks on the pavement surface [7].

The implementation of recycled aggregate in mineral-cement-emulsion mixtures can contribute to reducing the stiffness of these materials. However, a recycled aggregate content below 30% of the mixture weight does not significantly affect the tensile strength of the analyzed materials [8].

Various types of waste can also be implemented into MCE mixtures for reuse without compromising the mechanical properties of the mixtures. The additions to recycled mixtures include: rubber granulate [9], construction and demolition waste [10-11], and mineral materials from recycled concrete pavements [12].

Asphalt binders influence on physical and mechanical parameters such as indirect tensile strength, creep modulus, and void content of cold-recycled mixtures [13-14]. One of such binders used in pavement construction is asphalt emulsion. It is a mixture in the form of a suspension of fine asphalt particles in water. The stability of this mixture is achieved by adding emulsifiers and stabilizers. Over time, the water evaporates from the emulsion, leaving only the asphalt binder in the mixture or on the sprayed surface. The use of asphalt emulsion in road mixtures is characterized by rapid compaction, flexibility and resistance to weather conditions.

It has been demonstrated that asphalt emulsions can be used as a repair agent for surface cracks in layers made of porous mixtures. The penetrating properties of asphalt emulsions can be enhanced by the use of refreshing additives, so-called rejuvenators, in the form of aromatic oil or biomass oil [15]. Asphalt emulsions can also be used to spray asphalt layers to improve their surface properties (e.g., to close microcracks or improve interlayer adhesion).

The research [16] demonstrated that the use of anionic asphalt emulsion in mineral-cement-emulsion mixtures can result in lower yield point and viscosity compared to cationic emulsions.

In the MCE mixtures, increasing the emulsion content led to more viscoelastic behavior, which was indicated by lower stiffness moduli and higher phase angles [17].

Furthermore, when the asphalt emulsion to cement ratio by weight (AE/C) is 0.4, the semi-flexible pavement layer can have better fatigue resistance than the conventional asphalt mixture [18] and better rutting resistance [19]. Adding asphalt emulsion to the cement paste increases the elasticity and ductility of the semi-flexible pavement, but reduces its average tensile strength and stiffness [20].

The asphalt emulsion presence resulted in a reduction in thermal shrinkage. It should be noted that the interaction between cement and asphalt emulsion in MCE affects both, the fresh and cured mixture and involves complex physical and chemical processes connected with two aspects: the adsorption of asphalt emulsion with cement and the destabilization of asphalt emulsion, as was demonstrated in [21]. In a mixture with a low asphalt/cement ratio, anionic asphalt emulsion should be used to improve liquidity, while a mixture with a high asphalt/cement ratio should be prepared using cationic asphalt emulsion to ensure good bonding at an early stage. Similar issues were analyzed in [22]. The viscosity and yield point of asphalt emulsion increase with the emulsifier dosage. This is probably due to the fact that asphalt drops may become smaller with higher emulsifier content during the asphalt emulsion production process.

Mixing and compaction can reduce the air void content and significantly increase the indirect tensile strength *ITS* of MCE mixtures with asphalt emulsions and high cement content [23]. Attention should also be paid to the mixing method. Cement and asphalt emulsion should be fully mixed before contact between the aggregate and mortar to achieve optimal cold-recycled mix performance and avoid the adverse interface formation [24]. In mineral-cement-emulsion mixtures, the cement content increases the strength and stiffness values, while the emulsion content makes the mixture more flexible and less susceptible to cracking [25].

During the curing period, the MCE mixture exhibits viscoelastic properties, even with an increased cement content of up to 6%. However, adding cement as a binding agentinfluences the compacting process – the growth of the dynamic moduli of the tested mixtures was observed [26].

The phenomenon of stiffness reduction in MCE mixtures can be beneficial when these materials are used for road pavement base layers. This stiffness reduction significantly increases the fatigue life of the layer, especially during cracking phase [6]. Using the innovative binders based on dust by-products instead of cement, combined with asphalt emulsion as a cohesive binder, can also reduce shrinkage and increase the crack resistance of mineral-cement-emulsion mixtures.

In the context of the MCE materials production technology the rheology plays a significant role, especially when MCE is designed with high amounts of recycled asphalt pavement. In [27], the authors analyzed models describing the behavior of materials containing a hydraulic material – cement and a flexible material – asphalt binder. Based on the modeling, the relationship between the dynamic modulus and the loading frequency was described.

Experiments demonstrated that during the initial bonding phase of the MCE mixture, the rheological properties are dominated by the interaction of cement particles, which can adsorb plasticizer molecules and asphalt drops [28]. This plasticizer causes the release of asphalt drops from the emulsion and improves the rheological behavior of the mixture. The addition of a copolymer in the form of a polymer powder increases the viscoelastic properties – the phase angle rises comparing to the reference mixture [29]. The research results presented in [14], [30] confirmed that the MCE mixture is characterized by both elastic and viscoelastic properties.

The results presented in [31] showed that the type of binder added to mixtures containing RAP and cement has a significant impact on the complex stiffness modulus. Furthermore, increasing the reclaimed asphalt pavement content resulted in a lower modulus.

A cold-compacted MCE mixture achieves a specific tensile strength due to factors such as aggregate friction, cohesion, and capillary activity [32]. Binder cohesion is essential for ensuring the mixture's stiffness, tensile strength, and durability. Higher cement content in the mixture improves asphalt coalescence, accelerating the process of asphalt precipitation from the emulsion by binding water.

1.2. APPLICATION OF AN INNOVATIVE BINDER BASED ON UCPP

To reduce global CO_2 emissions from cement production, research is underway into sustainable alternatives to conventional Portland cement. One proposed solution is to use byproducts or waste to create sustainable binders. Cement kiln dust (so-called cement bypass dust) is being investigated as a potential activator for pozzolanic materials. The use of innovative cement binders based on cement-dusty by-products (UCPP) is a way to improve the properties of asphalt mixtures containing RAP [33].

The primary component of Portland cement is clinker. During clinker production, modern kiln installations also generate unprocessed UCPP waste dust. This waste can contain significant amounts of soluble alkali and free lime. Their presence in the binder can potentially act as an activator for other binder components [34].

Chemical industry byproducts can also be used in Portland cement production. The presence of chlorides and sulfates in cement clinker burning processes removes alkalis from raw material mixtures, converting them into volatile forms, accelerating the decomposition of mineral raw materials and accelerating the formation of cement minerals [35].

Cement-dusty by-products are used in various industries. Attempts have been made to use these wastes in the production of protective glass for optics. A new method for removing dust waste from cement production using an active glassy environmental system was described in [36]. It was demonstrated that the material obtained in this way can be used for radiation protection.

Recycling issues and the environment protection force the intensification of raw material waste utilization. Therefore, recycling is also a widespread phenomenon in the road construction industry. This also applies to the reuse of white cement bypass dust (WCBPD). The use of these materials in self-compacting concrete can contribute to a significant reduction in this waste. The use of WCBPD at levels below 10% does not reduce the strength or durability of concrete, while levels up to 25% allow for the production of concrete with a compressive strength exceeding 40 MPa [37].

As a binder additive, UCPP waste dust can replace traditional cement. It acts as a stabilizer and reduce the stiffness of the conglomerate material. The use of UCPP dust in MCE mixtures is also a waste disposal method [38]. An additional component of the innovative binder will be hydrated lime, which improves the properties of the mixtures and the adhesion of binders to aggregate [39].

The significant variability in the composition of this dust makes it important to conduct research to verify the potential use of this type of waste in construction. The study [40] compared three-component mortars containing various percentages of dust, blast furnace slag and cement.

Mortars containing high-sulfate binders have a higher water consumption than mortars containing high-lime binders and produce stiffer mixtures. Consequently, these materials will also bind faster. However, high-lime binders are significantly more reactive and have a higher heat of hydration than high-sulfate binders. This is attributed to the highly exothermic reaction between lime and water.

Using X-ray fluorescence and X-ray diffraction to analyze the chemical composition of cement dusty by-products and scanning electron microscopy with X-ray microanalysis to analyze the microstructure, surface features, and elemental composition of the materials, the HCl removal efficiency of the by-product was investigated [41]. The HCl removal efficiency of UCPP initially increased with increasing reaction temperature and then decreased. The best results were obtained at 600°C. Lime is the main substance responsible for HCl removal.

In search of a method for UCPP disposing as hazardous waste, active binders based on slag and UCPP were developed, modified with the addition of 10% microsilica (S) and/or various doses of TiO_2 nanoparticles in the presence of an alkaline activator [42]. Adding 1% TiO_2 to a mixture containing 10% of microsilica and 20% of UCPP dust significantly improved the mechanical properties of the slurries. Zeolite-like phases were formed in slurries subjected to hydrothermal hardening, contributing to higher compressive strength.

Industrial byproducts such as ground granulated blast furnace slag, fly ash, and cement-dusty by-product can be used as binders with good mechanical and chemical properties. Cement-dusty by-product enhances the geopolymerization reaction because it contains alkali oxides such as Na_2O and CaO [43]. Scanning electron microscopy (SEM) images show that geopolymer materials have a compact and non-porous matrix structure, which is a result of hydration.

Replacing blast furnace slag mixtures with 20-30% of cement-dusty by-product increases compressive strength and bulk density while reducing total porosity [44]. It is recommended that the optimal mixture composition contain 20% UCPP – this allow to achieve lower porosity and high compressive strength, bulk density, and absorbed water content.

Cement dust is a byproduct of the cement industry, characterized by unfavorable properties. Its mechanical properties can be improved by mixing it with 20% iron slag, another industrial waste generated during steel production, and a small amount of 0.1% nanosilica [45]. Such composite can be considered an effective matrix for the safe stabilization of radioactive waste, even under extreme conditions, such as flooding.

The research results presented in [46] showed that mixtures containing foamed asphalt, reclaimed asphalt, and a cement-dusty by-product additive exhibited adequate mechanical properties. However, it is important to maintain the appropriate proportion of the components. As a result of optimization, the recommended composition for the mixed binder was determined: 40% cement, 20% hydrated lime, and 40% UCPP. This proportion positively increased the *ITSR* parameter and the indirect tensile strength *ITS*. In turn, excessive $Ca(OH)_2$ content in the road binder, may reduce the usability of the recycled base layer.

The literature research showed that it possible to implement various waste materials including cement-dusty by-products to construct road pavement base layers. Implementation of UCPP materials can help to protect the environment by reducing the natural materials consumption and to decarbonate the MCE mixture production process.

2. MATERIALS AND METHODS

2.1. PURPOSE OF RESEARCH

The aim of the analyses was to verify the suitability of UCPP binders for use in MCE mixtures in terms of reducing thermal and shrinkage cracking. The study demonstrated the effect of binders on the properties of the mixtures compared to conventional cement. A series of laboratory tests were conducted to investigate the specific behavior of MCE mixtures in base road layers. Crack propagation in the mixtures, caused by increased loads and thermal cracks growth, were analyzed. The experiment resulted in selecting binders that achieved the greatest reduction in these cracks in MCE conglomerates. This article focuses on fine-grained mixtures as a material that meets the design criteria.

2.2. MATERIALS

Mineral-cement-emulsion (MCE) mixtures are used for the base layer of road pavements constructions. The MCE mixture consists of reclaimed asphalt, aggregate improving the gradation, asphalt emulsion, cement, and water.

Tests were conducted for eight MCE mixture variants. Fine-grained mineral mixtures were used, for which seven various binder contents were prepared [47-48]. They differed in the content of three components (cement, hydrated lime, and cement-dusty by-products UCPP) – Table 1. A fine-grained reference mixture (Ref), using cement as the binder, was also used in the test plan. The fine-grained mixtures were assigned the following designations: 1V, 2V, 3V, 4C, 5C, 6C, 7C, Ref.

Table 1. Content of ingredients in a dedicated binding agent [48]

Symbol of binder	Binder components [–]		
	Cement	Lime	CBPD / UCPP
1V	0.20	0.20	0.60
2V	0.20	0.60	0.20
3V	0.60	0.20	0.20
4C	0.20	0.40	0.40
5C	0.40	0.20	0.40
6C	0.40	0.40	0.20
7C	0.33	0.33	0.33
Ref	1	0	0

The mineral mixture contained: natural aggregate (melaphyre) with a continuous grain size of 0/31.5 mm, natural aggregate (washed sand) with a continuous grain size of 0/2 mm, and recycled aggregate (reclaimed asphalt) with a pieces size of 0/10 mm. The content of asphalt binder in the reclaimed asphalt was equal 5.3%. The softening point temperature of the recovered asphalt was equal 58°C.

A composition design of the recycled MCE mixtures was prepared. The percentages of individual components are presented in Table 2.

The use of a binder in MCE mixtures was intended to ensure operational durability and reduce cracking in road pavement layer.

Table 2. Composition of the MCE mixture

Mixture components	Mineral mixture [%]	Mineral-cement-emulsion mixture (Ref) [%]
0/10 reclaimed asphalt 10 RA 0/8 mm	40	34.40
0/31.5 crushed aggregate improving the gradation – melaphyre	50	43.00
0/2 natural aggregate improving the gradation – sand	10	8.60
Binder	–	3.00
Asphalt emulsion C60B10ZM/R	–	5.00
Water	–	6.00

Fig. 1. Semi-cylindrical samples drilled from a compacted slab

Fig. 2. Samples with the cut

Fig. 3. The SCB test scheme

2.3. METHODS

Detailed tests of low-temperature crack resistance were performed using the SCB method, according to [49]. For crack propagation analyses in the half-cylindrical bending test, samples with a nominal radius $R = 75$ mm and a thickness of 50 mm were used for each batch and a characteristic temperature of 0°C. The samples were compacted with a rolling device using slip plates according to [50] until the bulk density determined on the Marshall samples was achieved. Due to the presence of cement and hydraulic binders in the mixtures, the curing period was 28 days. Core samples $\Phi = 150$ mm were then drilled from the compacted slab and cut to the required nominal dimensions. A view of the half-cylindrical samples was shown in Fig. 1. After obtaining the half-cylindrical sample, the so-called fatigue notch was modeled on the bottom of the sample in the middle of its radius. The notch was 10 mm deep and 1 mm wide. The view of the sample with the cut is shown in Fig. 2.

During the tests, the loading force required to break the sample and the vertical displacement were recorded. The value of the breaking force was used to determine the tensile strength at failure. The value of the vertical displacement, related to the sample height (actual radius), allowed for the estimation of the breaking strain at the moment of crack formation. The final parameter describing the resistance of the tested material to cracking at low temperatures was the fracture toughness K_{Ic}. The sample loading diagram was shown in Fig. 3.

During the test, three parameters were analyzed: the strain at failure ε_{max} (1), the stress occurring in the material at failure σ_{max} (2) and the so-called fracture toughness, expressed by the parameter K_{Ic} (3):

$$\varepsilon_{max} = \frac{\Delta W_i}{W_i} \cdot 100\%, \tag{1}$$

$$\sigma_{max} = \frac{F_{max}}{D_i \cdot t_i}, \quad (2)$$

$$K_{Ic} = \sigma_{max} \cdot \sqrt{\pi \cdot a_i} \cdot f\left(\frac{a_i}{W_i}\right), \quad (3)$$

where:

ε_{max} – maximum failure strain [%],
σ_{max} – maximum failure stress [N/mm^2],
K_{Ic} – fracture toughness [N/mm$^{1.5}$],
W_i – sample height [mm],
ΔW_i – vertical displacement under the influence of the maximum force [mm],
F_{max} – maximum failure force [N],
D_i – sample diameter [mm],
t_i – sample thickness [mm],
a_i – notch depth [mm],
f – form factor [–].

The SCB tests were carried on four samples for each MCE mixture variant.

Analyses of the MCE material's resistance to shrinkage and thermal cracking were performed using the UTST method, according to [51]. For the tensile strength and fracture toughness analyses, beam-shaped samples with nominal dimensions of $a = 50$ mm (width), $b = 50$ mm (height), and $h = 160$ mm (length) were used for each batch and a characteristic temperature of 0°C. The samples were compacted with a rolling device using slip plates according to [50] until the bulk density determined on Marshall samples was obtained. Due to the presence of cement and hydraulic binders in the mixtures, the slabs were cured for 28 days. Samples were cut from the compacted slab to the required nominal dimensions. A view of the samples was shown in Fig. 4. The samples were glued to elements mounted in the testing machine. A view of the glued sample was shown in Fig. 5. An epoxy adhesive glue was used – with very high strength and resistance to high and low temperatures.

During the tests, the loading force required to destroy the sample and the displacement were recorded. The value of the breaking force was used to determine the stress, which represents the sample's tensile strength. The value of the vertical displacement, related to the sample height, allowed for the estimation of the breaking strain at the moment of crack appearance. The sample loading scheme was shown in Fig. 6a. In Fig. 6b the typical sample failure was presented.

Fig. 4. Samples cut from a compacted slab

Fig. 5. Glued sample

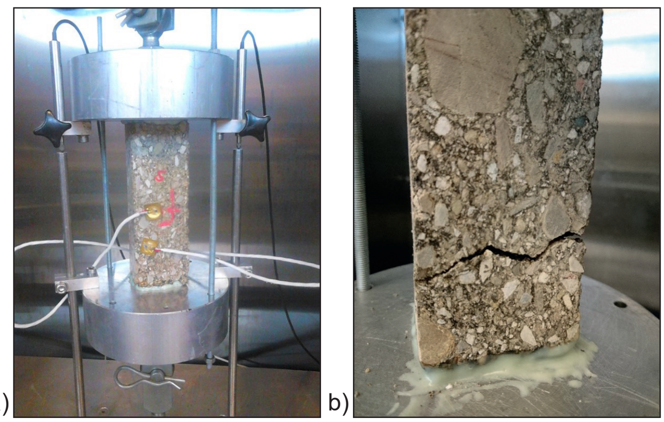
a)  b)

Fig. 6. UTST test: a) sample loading scheme, b) sample failure scheme

During the test, two parameters were analyzed: the failure strain $\varepsilon_{failure}$ (4) and the stress at failure β_t (5):

$$\varepsilon_{failure} = \frac{d_{max\,i}}{L_i} \cdot 100\%, \quad (4)$$

$$\beta_t = \frac{F_{max}}{a_i \cdot b_i}, \quad (5)$$

where:

$\varepsilon_{failure}$ – failure strain [%],

β_t – maximum failure stress [MPa],

d_{max} – maximum displacement at sample failure [mm],

L_i – sample length [mm],

F_{max} – maximum force [N],

a_i – sample width [mm],

b_i – sample height [mm].

The UTST tests were carried on three samples for each MCE mixture variant.

3. RESULTS

3.1. SCB TESTS

Based on the obtained results, the average values of the maximum failure stress, the failure strain and the fracture toughness K_{Ic} were determined for all tested MCE mixtures (Figs. 7-9).

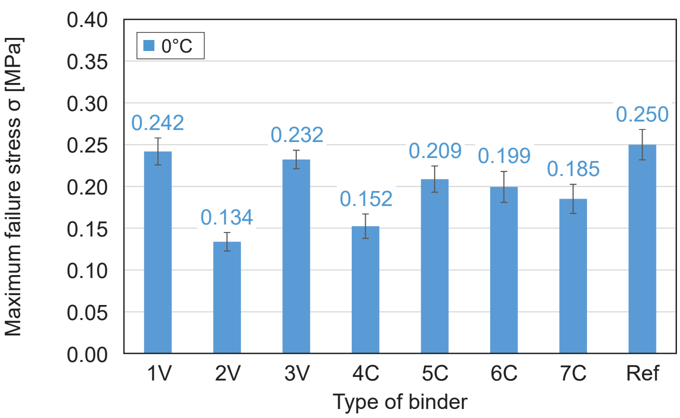


Fig. 7. Maximum failure stress (SCB)

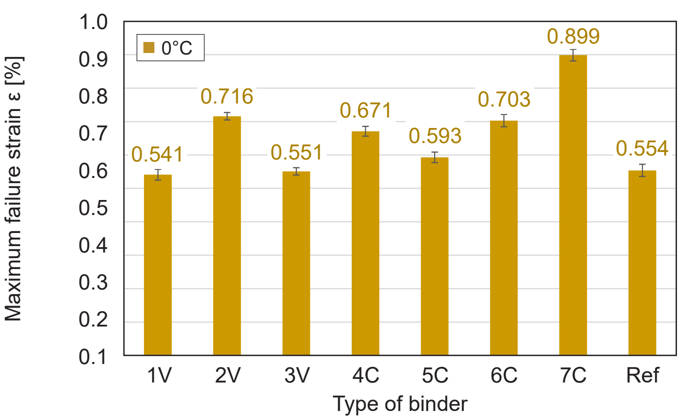


Fig. 8. Maximum strain at fracture (SCB)

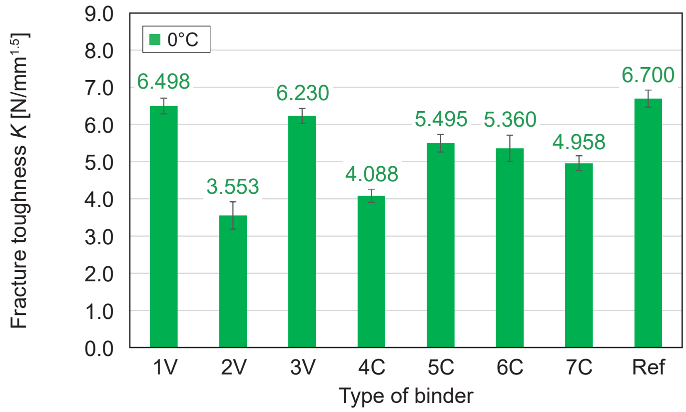


Fig. 9. Fracture toughness (SCB)

Based on the results analysis, it was found that the use of innovative binders instead of standard cement affected the material properties of the MCE mixtures. Stresses decreased, particularly for binders 5C, 6C, and 7C. The use of UCPP binder in the mixtures increased the failure strain of the MCE, especially for 7C. This indicates that this binder may have a positive effect on the crack resistance of MCE mixtures and limit their propagation in the road base layers. The fracture toughness coefficient K_{Ic} for most mixtures is similar, although mixtures 2V and 4C are characterized by lower values. This may suggest lower fracture toughness of these mixtures and worse behavior under stress.

3.2. UTST TESTS

Based on the obtained detailed results, the average values of the maximum stress at sample failure and strain were determined for all tested MCE mixtures (Figs. 10-11).

The use of UCPP binders reduced stresses compared to the reference mixtures. This means that UCPP binders can reduce the possibility of cracking in MCE mixtures. The best results were obtained for 2V and 4C binders. However, for these mixtures, the analyzed stiffness (analyses are provided in other publications [52]) was one of the lowest, which may affect the stress values. The most advantageous stress results with adequate stiffness of the material, were obtained for 6C and 7C binders.

An additional element was the study of the failure strain. In this case, all UCPP binders increased the strain at fracture. This can be interpreted as the better MCE base layer load-bearing capacity (thermal and operational). Significant increases were observed for binders 1V, 2V, 3V, 6C, and 7C.

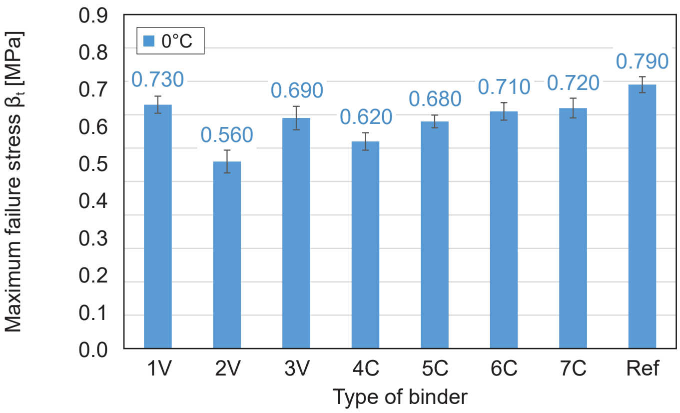


Fig. 10. Maximum failure stress (UTST)

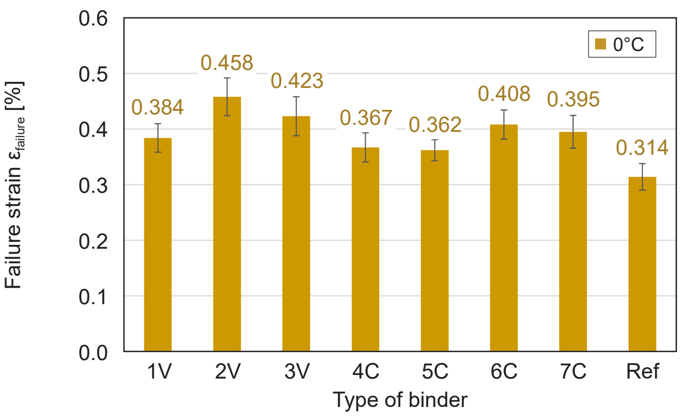


Fig. 11. Maximum strain at fracture (UTST)

4. DISCUSSION

The obtained results allowed for a comparison of the failure stresses and strains at failure for the two different test methods. The comparative analysis demonstrated a good correlation between the failure stresses in the SCB and UTST tests (Fig. 12).

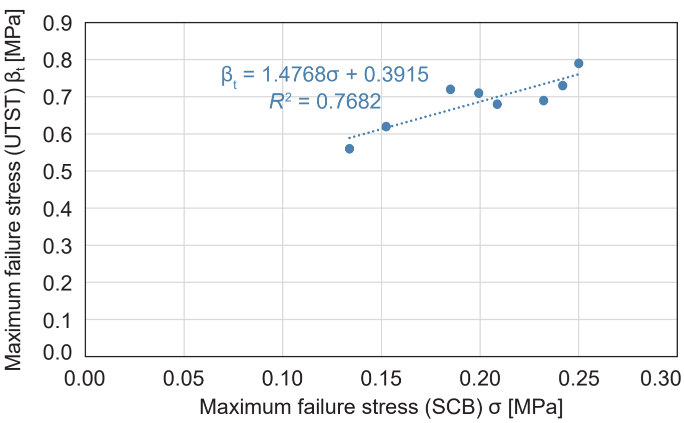


Fig. 12. Dependency between stress in SCB and UTST tests

The coefficient of determination R^2 was 0.77. For comparisons of strains, no satisfactory correlation of the test results was obtained (Fig. 13). The coefficient R^2 was only 0.11.

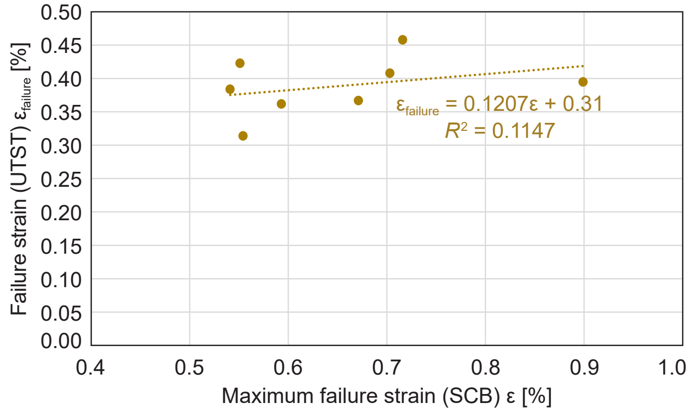


Fig. 13. Dependency between strains in SCB and UTST tests

The statistical dispersion in the results was significant, reaching up to 50%. This is due to the different loading scheme of the samples and their behavior during failure.

Comparisons of the failure stresses indicate the homogeneity of the MCE mixtures across the different test methods. This demonstrate the good material properties of the MCE mixtures based on the UCPP binder.

A positive effect on limiting the cracking and the crack growth was also observed during a detailed analysis of the displacement rate in the SCB tests (Fig. 14). The nature of dependency between force and displacement was compared for selected MCE mixtures.

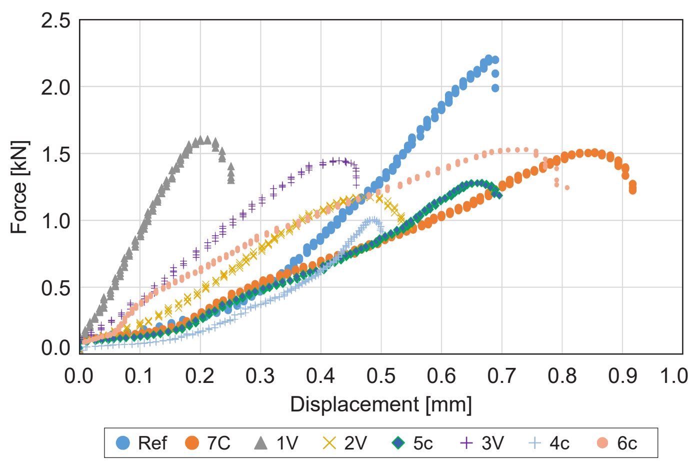


Fig. 14. Dependency between force and displacement in the SCB method

When comparing the reference MCE mixes with those using UCPP dust, the use of the innovative binder resulted in a decrease in the failure force in all cases. For mixes containing 6C and 7C binders, a reduction in the failure force was observed with a simultaneous increase in the displacement at failure. For mix 5C, a decrease in the force was observed while maintaining a comparable displacement at failure to the reference mix. The use of UCPP binders also reduced the stress increase rate (angle of inclination) compared to the mix with conventional cement, with the exception of 1V mix. Mixes 1V, 2V, 3V, and 4C achieved lower displacement values with a simultaneous low failure force.

5. CONCLUSIONS

From the conducted research cycle and analysis of the results the following conclusions can be drawn:

1. The use of cement-dusty by-products (UCPP) influence on the strain and strength properties of MCE mixtures.
2. The use of MCE mixtures containing 40% reclaimed asphalt by weight in base layers will allow for the effective implementation of recycling technology.
3. In the road pavement construction base layers, it is possible to use MCE-type mixtures containing UCPP binder, replacing traditional cement.
4. Compared to mixtures based on traditional cement, a decrease in the failure stress was observed in mixtures containing UCPP. Simultaneously the increase in the strain at the failure was observed in mixtures containing UCPP dust.
5. Research and analyses indicate a positive effect of UCPP additives on the resistance of MCE mixtures to cracking at low temperatures.
6. Using binders based on UCPP instead of traditional cement will reduce the stiffness of the road base layer and limit the cracking. This will increase the durability of the entire road pavement construction.
7. The dependency of the failure stresses obtained using the SCB and UTST methods remains linear and indicates the homogeneity of MCE mixtures containing UCPP binders.
8. In the SCB tests the analysis of the strain rate showed a positive effect on limiting cracking and crack growth.
9. The use of UCPP binder in MCE mixtures resulted in a reduction of force with increased displacement and a reduction in the stress rate. This led to a postponed cracking phenomenon.
10. An additional benefit will be the disposal of Portland cement production waste and improving the environmental protection.
11. The use of UCPP dust instead of conventional cement to produce a binder dedicated to MCE mixtures will contribute to the decarbonization of the MCE mixture production process and increase the efficiency of road pavements recycling.

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Ograniczanie spękań mieszanek MCE stosowanych w warstwach podbudowy

Streszczenie: Przedmiotem przeprowadzonych w artykule analiz są mieszanki mineralno-cementowo-emulsyjne (MCE) zawierające destrukt asfaltowy (RAP). W mieszankach zastosowano innowacyjne spoiwa drogowe oparte na ubocznych cementowych produktach pylastych (UCPP). Spoiwa te stosowane w zamian klasycznego cementu mogą ograniczyć sztywność otrzymanego konglomeratu, co wpłynie na zmniejszenie spękań temperaturowych w warstwach podbudowy nawierzchni drogowych. Spoiwa UCPP mogą również przyczynić się do dekarbonizacji procesu produkcji mieszanek MCE. W przeprowadzonych badaniach wykazano znaczący wpływ spoiw UCPP na właściwości mechaniczne recyklowanych mieszanek MCE. Analizowano propagację spękań w badaniach metodą SCB oraz UTST. W wyniku przeprowadzonych prac wytypowano spoiwa, które w największym stopniu pozwalały na ograniczenie spękań i prędkości ich przyrostu. Powyższe analizy przyczyniają się do szczegółowego rozpoznania problemu dotyczącego efektywnego stosowania mieszanek MCE z destruktem asfaltowym w konstrukcji nawierzchni drogowych.

Słowa kluczowe: mieszanka mineralno-cementowo-emulsyjna, propagacja spękania, recycling, uboczne cementowe produkty pylaste (UCPP).