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The Experimental Assessment of the Deformability of Cement and Cement-asphalt Matrices with Rubber Powder Additive by Application of DIC System

J Kukiełka[1,*] and T Sadowski[2]

[1] Department of Roads and Bridges, Lublin University of Technology, Nadbystrzycka 40 str., 20-618 Lublin, Poland

[2] Department of Solid Mechanics, Lublin University of Technology, Nadbystrzycka 40 str., 20-618 Lublin, Poland

Abstract. The paper presents an experimental study of deformability of beams made of cement and asphalt-cement matrices with addition of rubber powder 25÷40% in relation to binders. 4-Point Bending (4-PB) tests were performed with series of specimens after 28 days of hardening. Tests were done at various temperatures, i.e. 5°C, 23°C and 50°C. Monitoring of deformation process was fully recorded by Digital Image Correlation (DIC) system ARAMIS up to the final failure.The cracks in the asphalt-cement matrices with rubber powder initiate when stress state exceeded about 50% of their flexural strength (fct,flex2). The obtained experimental results lead to the general conclusion that addition of rubber powder to different matrices causes increase of deformability, from 2 to 3 times in relation to the pure cement matrix. Moreover, it can be stated that composite materials such as asphalt-cement concrete (ACC), mineral-cement-emulsion mixes (MCEM) with rubber powder additive are more flexible in comparison to the pure cement concrete (CC),

1. Introduction

Composite materials, for instance cement concretes (CC), asphalt-cement concretes (ACC), mineral-cement-emulsion mixes (MCEM), as well as those with added rubber powder, are considered to be heterogeneous. Different types of matrices, as a continuous phase of such complex materials and inclusions reinforcing a matrix, are essential components of composite structures. Therefore, the overall properties of considered composites depend on mechanical properties of matrices and inclusions.

In Western Europe and the USA asphalt-cement matrices made by adding asphalt emulsion (AEm) to cement paste are most frequently used in roads recycling; in such matrices the amount of cement in recycled mineral mix usually does not exceed 2%. Cement accelerates asphalt emulsion setting and the initial strength of the mix [1, 2, 3, 4, 5, 6]. The MCEM containing more than 2% of cement have properties similar to those of cement-stabilised mineral mixes [5].

The proposed addition of rubber powder to the MCEM should contribute to improved durability and reduced resilient modulus, as may be concluded from preliminary research [7].

The use of waste tires in road construction was described in the monograph based on the review of national and foreign research [8].

Chippings and granules were used in numerous lab tests of cement concretes intended for the construction of yards and playing fields while crumb rubber was used for instance as an addition to hot asphalt in “dry process” or “wet process” technology [9]. Crumb rubber in “dry process” is added to

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mixing plant in the amount of 3÷4% of the mix mass. Hot mix-asphalt with added crumb rubber shows increased resistance to temperature changes, for instance to thermal cracks in road pavement layer. Asphalt-rubber binders used for surface treatment and crack relief layers are known from a few industrial technologies, e.g. McDonald [10] or SAMI (Stress Absorbing Membrane Interlayer) [11]. The properties and usability of crumb rubber depend on the rubber type, manner of grinding, shape of particles, specific surface and modification manner [9, 12, 13].

Asphalt pavements are generally designed based on two criteria:

(1) asphalt concrete fatigue,

(2) subgrade compressive strain.

The asphalt concrete fatigue equation contains calculation of tensile strain in the bottom of asphalt layer [14]. According to this criterion the destructive tensile strain of asphalt mixture should be specified. Different fatigue criteria should be applied to pavement with the MCEM. For instance in publication [15] fatigue equation of pavement with the MCEM was proposed and the minimal level of damage strain which guarantees one million load cycles was established $\varepsilon_6 = 170 * 10^{-6}$ m/m – for fatigue damage parameter equal to $D_f = 30\%$.

In this paper we present results of the 4-PB deformation tests on the above composites with different matrices, starting from purely elastic response, cracks initiation and their further propagation up to the final failure.

In order to test deformation stages we used beams of dimensions 250×50×50 mm made of cement or asphalt-cement matrices with addition of rubber powder. The whole deformation process was recorded using the 3D optical DIC system ARAMIS, which is very useful in case of many different construction materials, e.g. [16-26]. Deformation analysis makes it possible to determine the deformation value in the tested specimen plane from 0.05% to >100% with accuracy of 0.01 % [27]. The system allows to locate cracks and trace their propagation from the width of 0.01 mm [16, 17, 28] and was successfully used in works concerning concrete resistance to cracks for the analysis of initial cracks propagation [28, 29, 30, 31].

2. Materials used for matrix preparation

In accordance with Polish requirements concerning the MCEM [3] Portland cement CEM I or Portland composite cement CEM II class 32.5 or 42.5, which complies with the requirements of PN-EN 197-1 standard "Cement. Part 1. Composition, requirements and conformity criteria for common-use cements" should be used. Portland cement CEM I 42.5 R was adopted to make matrices.

Currently, in deep cold recycling slow-setting overstable asphalt emulsion C60 B10 ZM/R as per PN-EN 13808:2013-10 is used and replaces previous C60 B5 R emulsion as per PN-EN 13808:2010. Asphalt emulsion C60 B5 R was adopted to make matrices.

The rubber powder used in tests was made by milling rubber at room temperature to obtain 0/1 mm grading.

3. Specimen preparation and testing

The subject of research were the following compositions of matrices (W – water, CEM – cement, AEm – asphalt emulsion, RP – rubber powder) :

A – W:CEM = 1:2 – cement matrix with known properties in the case of concretes [32] is also used in lean concretes and aggregates stabilised with hydraulic binders,

B – CEM:RP = 1.5:1 – cement matrix with added rubber powder used in standard and lean concretes [33, 34, 35],

C – AEm:CEM = 3:5 – asphalt-cement matrix with dominant content of cement which occurs in most mixes used in cold recycling in Poland [3],

D – AEm:CEM:RP = 1:1:1 – asphalt-cement matrix with added 0/1 mm rubber powder with the same content of components (m/m),

E – AEm:CEM:RP = 1:1.5:1 – asphalt-cement matrix with added 0/1 mm rubber powder with increased content of cement (m/m),

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F – AEm:CEM:PR = 1:2:1 – asphalt-cement matrix with added 0/1 mm rubber powder with the cement content corresponding to the content of the remaining components (m/m).

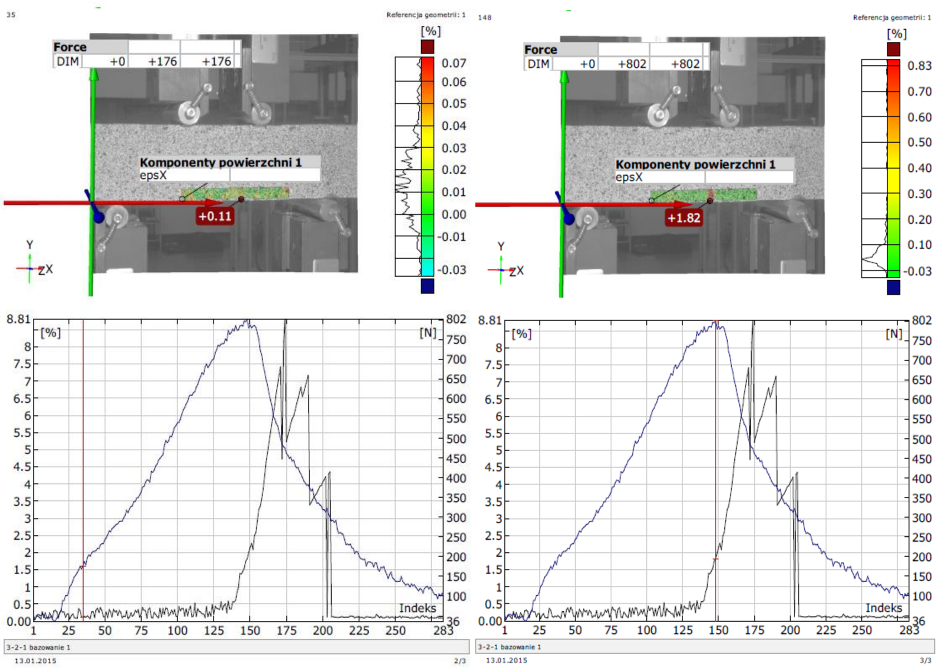
From each matrix composition 9 beams of 250×50×50 mm in dimensions were made. All the matrix compositions had the W/CEM ratio within the range of 0.5÷0.6 in order to obtain plastic consistence and to prevent segregation of components in the moulds. The specimens were consolidated by gravitational compaction and were left in moulds for 24 hours; after this time they were demoulded and stored for 28 days in room temperature, protected from water evaporation.

To obtain strain fields using the ARAMIS system it is necessary to introduce points pattern on the specimen surface, which is scanned by the DIC system and then its digital image is created. In the experimental tests it was assumed that vertical displacement rate of the loading head during 4-PB process was equal to 0.2 mm/min. The DIC system enables saving the entire deformation test as a video, which makes thee analysis of the whole specimen destruction process possible from the beginning of loading until its destruction [27].

The horizontal tensile strain measurements ε_t were concentrated in a central bottom part of the specimen, between the points at which loading was applied. The analysed fragment of the specimen has length and height equal to approximately 50 mm and 10 mm, respectively.

4. The results of asphalt cement matrices tests

The flexural strength in the 4-PB tests were performed in temperatures 5°C, 23°C and 50°C. For each matrix composition we prepared 3 beams, which were stored for at least 4 hours in a climate chamber prior to the test. The experimental tests were performed immediately after the specimens were removed from the chamber. The sample deformations ε_t were measured by application of the ARAMIS and were presented in Fig. 1.



Initiation of crack Destruction of specimen

Figure 1. The 4-PB flexural strength of the beam made of the F matrix measured in 5°C

The results of experimental measurements and calculations are summarised in Table 1 and Fig. 2.

Table 1. The average values of tensile strains ε_t and flexural stresses for characteristic points of deformation processes of specimens made of cement and asphalt-cement matrices with added rubber powder.

Matrix	Temperature of tested beams [^{0}C]	Tensile strain initiating a crack ε_t [%]	Flexural stress at the moment of cracking σ_{flex2} [MPa]	Flexural strength $f_{ct,flex2}$ [MPa]	$\frac{\sigma_{flex2}}{f_{ct,flex2}}$
A	5	0.05	0.71	1.29	0.55
	23	0.07	0.37	0.67	0.54
	50	0.06	0.21	0.33	0.63
B	5	0.08	0.84	1.26	0.67
	23	0.23	0.52	1.03	0.51
	50	0.17	0.20	0.70	0.28
C	5	0.12	2.50	2.67	0.94
	23	0.10	0.88	0.97	0.91
	50	0.17	0.52	0.85	0.61
D	5	0.31	0.51	0.89	0.57
	23	0.16	0.28	0.64	0.44
	50	0.18	0.14	0.34	0.42
E	5	0.15	0.80	1.28	0.62
	23	0.13	0.56	0.78	0.72
	50	0.14	0.19	0.40	0.47
F	5	0.15	0.66	1.12	0.66
	23	0.17	0.29	0.51	0.56
	50	0.13	0.18	0.32	0.55

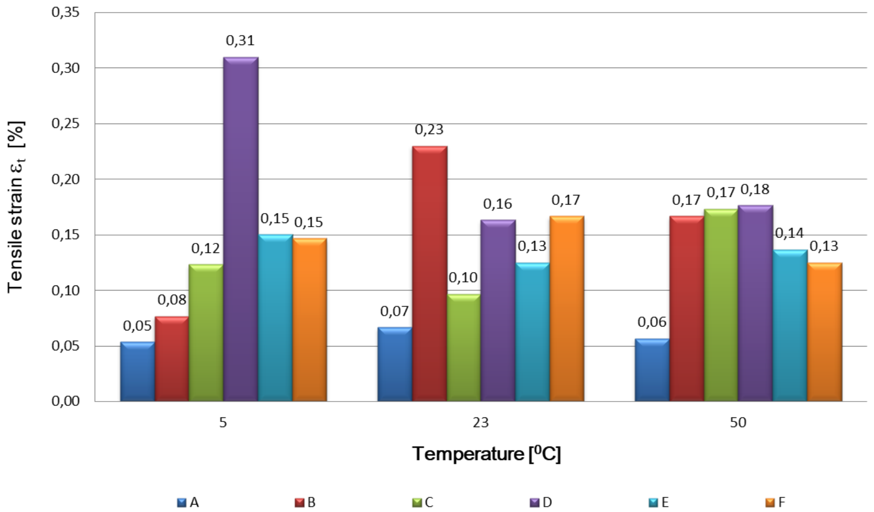


Figure 2. The values of the tensile strain ε_t initiating cracks during 4-PB strength tests for beams made of matrices: A, B, C, D, E, F after their maturing during 28 days and tested in 5°C, 23°C, 50°C.

5. Conclusion

(1) The performed tests of mechanical properties of specimens taken from cement and asphalt-cement matrices with addition of rubber powder reveal that deformability of the considered composites increased from 2 to 3 times in relation to cement matrix while influencing flexural strength 0,7 to 1,0 times.

(2) The cracks initiation in the AEm:CEM:RP matrices appears when stress exceeded about 50% of their flexural strength ($f_{ct,flex2}$). In case of the AEm:CEM matrix this stress was about 90% in temperature less than 23^{0}C. In temperature 50^{0}C cracks initiation took place respectively when stress exceeded 40% and 60% .

(3) The tensile strain corresponding to cracks initiation a in the cement matrix W:CEM = 1:2 was equal to ε_t =0.05% regardless of the test temperature. In case of the AEm:CEM:RP = 1:2:1 and AEm:CEM:RP = 1:1.5:1 matrices the appropriate values of strains were ε_t = 0.13÷0.15%. The largest tensile strain ε_t was obtained for matrices with high content of the rubber powder, i.e. for CEM:RP = 1.5:1 and AEm:CEM:RP = 1:1:1. The experimentally estimated tensile strain were equal to ε_t = 0.23% and ε_t = 0.31%, respectively.

(4) The influence of temperature on the threshold of critical deformations causing cracks initiation is not significant.

(5) One can conclude, summarizing, that the most important factor which influences the deformability of matrices is their composition and the amount of added rubber powder.

(6) It is necessary to formulate a numerical model describing the mechanical response of the beams including formation of the process zone in the crack tip and its propagation, e.g. [36 – 48].

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