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Tensile Properties of Polymer Repair Materials - effect of test parameters

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Abstract. In this research, five types of polymer repair materials were selected for investigation of the influence of sample shape, deformation rate and test temperature on the mechanical properties determined with an uniaxial tensile test. The results showed the clear effect of measurement conditions on tensile strength, elongation and modulus of elasticity. The highest tensile strength and modulus of elasticity were exhibited by epoxy resin for the filling of concrete cracks, which achieved 1% elongation. The lowest coefficient of dispersion characterized the results of tensile test carried out using dumbbell samples at a deformation rate of 50 mm/min. The effect of temperature varied with the material type.

Introduction

Static tensile test is basic method that is used to evaluate the mechanical properties of many construction materials. Results of tensile tests provide information about ultimate tensile strength, yield stress, elongation, elastic limit, reduction in area, Young's modulus, Poisson's ratio, etc. [1].

Factors affecting the tensile properties in case of polymer composites are various, such as the nature of matrix and filler, compatibility between them, technology and conditions of materials processing, the dispersion or distribution of filler/fibers in matrix, as well as interfacial structure and morphology, etc. [2-5]. Therefore, procedural details of the test vary for different polymers or polymer composites, especially in sample shape, sample size and deformation rate [6-9]. In general, the effect of test conditions on measured properties is known. However, available data in the literature mostly involve research reinforced polymer composites, e.g. [10, 12].

This paper presents the results of investigation on the influence of test conditions during uniaxial tensile test (sample shape, deformation rate and temperature) on mechanical properties of commercially available representative materials for protection of concrete structures, having different chemical compositions.

Experimental program

Five materials have been studied (Table 1): elastic polymer cement composite (PCC), epoxy resin for concrete injection (EP-1), thin epoxy protective coating (EP-2), epoxy industrial floors (EP-3) and polyurethane elastic pavements (PU). Five samples of each of these materials have been subjected to uniaxial tensile test based on various test parameters. EP-1, EP-2, EP-3 and PU samples were cured 7 days and PCC 28 days.

Examined polymer based materials have properties typical for materials without yield point (Fig.1). Based on the European Standards EN ISO 527, dumbbell and strap shaped specimens (Fig.2) and deformation rates 5, 50, 500 mm/min were chosen. The temperature during tests was 20 ^{o}C, whereas in analysis of temperature effect on the tensile strength it was equal to -20, 0, 20, 40 and 60 ^{o}C. The tensile strength, elongation and modulus of elasticity were evaluated for different combinations of measurement conditions. The details of the experimental program are presented in Fig. 3.

Table 1: General characteristics of tested polymer and polymer composites

Material	Basic ingredients	Application	Mix proportions
EP-1	A – epoxy resin, B – hardening agent	Crack injection, max crack width up to 0.3 mm	A:B = 7:1
EP-2	Water-borne epoxy resin	Thin protective coating approx. 0.5 mm thick	ready to use
EP-3	A – epoxy resin, B – hardening agent	Industrial floor; up to 3 mm thick	A:B = 4:1
PU	A – base resin, B – hardening agent	Elastic industrial floor; up to 3 mm thick	A:B = 3.3:1
PCC	A – cements mixture, fillers, modifier, B – water based dispersion of polymer	Elastic protective coating approx. 1 mm of thick	A:B = 7:3

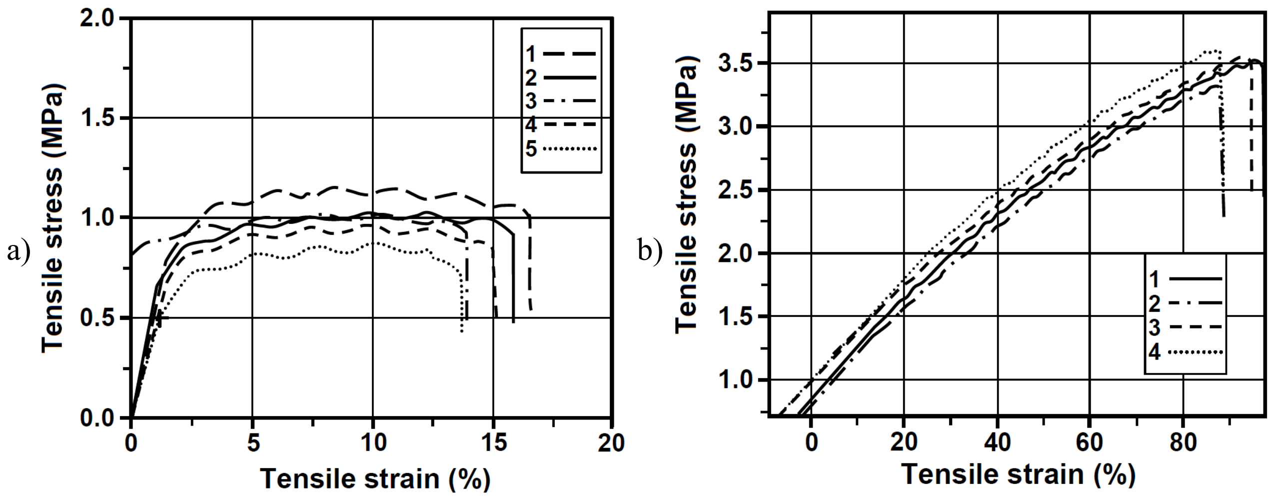


Figure 1: Examples of tensile test curves for: a) PCC and b) PU coatings recorded at 20°C and 50 mm/min

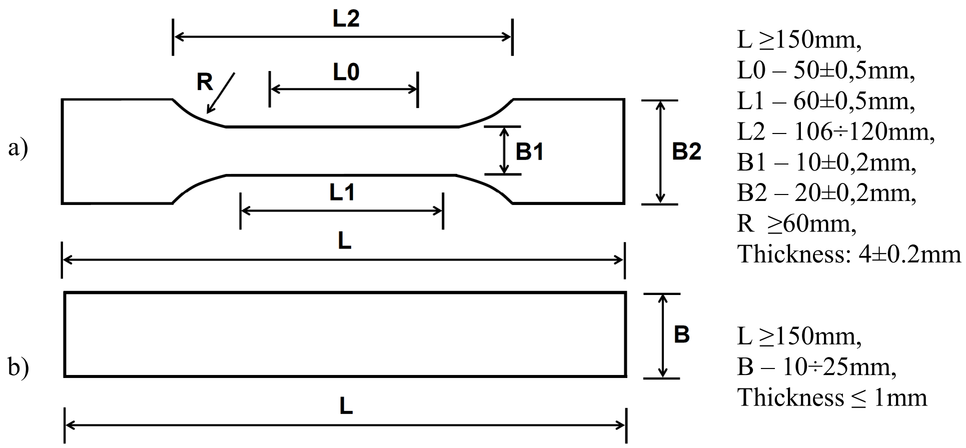


Figure 2: Specimen shape for uniaxial tensile test of polymers: a) dumbbell (type 1B, EN ISO 527-2: 2012) and b) strap specimen (type 2, EN ISO 527-3: 1998)

The tensile tests were carried out on an electromechanical testing machine INSTRON 5567. The load frame is operated under software control and can apply test loads of up to 30 kN with 0.4% load measurements accuracy. A high resolution digital camera is used to measure strain by tracking contrasting gauge marks placed on a specimen. Environmental chamber provides the ability to test materials behaviour at temperatures ranging from -70 to 350°C.

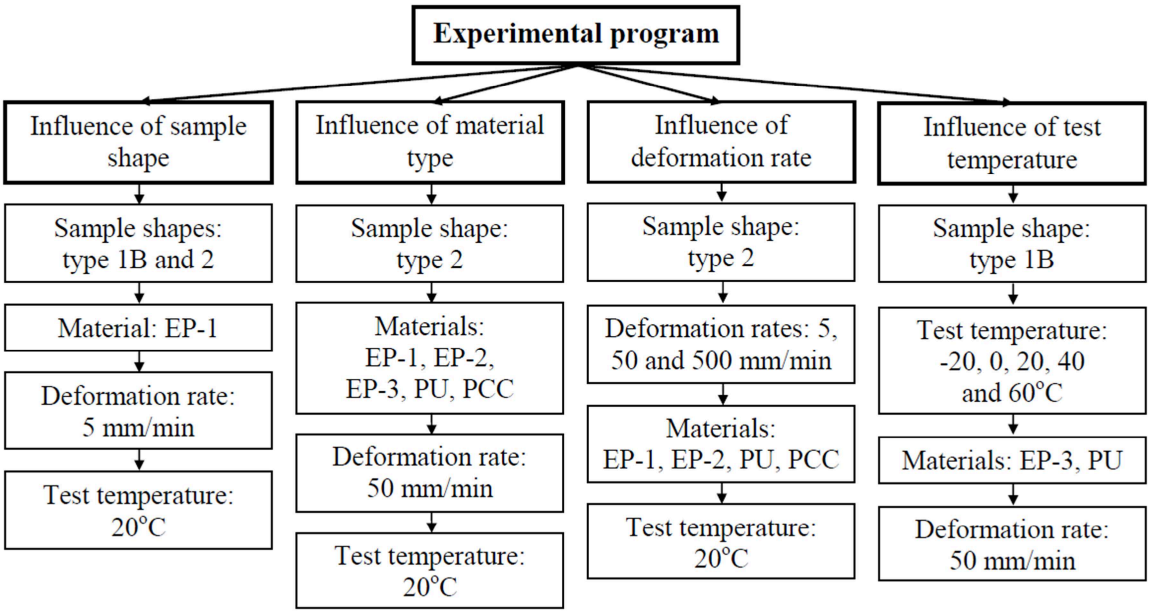


Figure 3: Scheme of the experimental program

Results

Effect of specimen geometry. In order to investigate the influence of sample shape, epoxy resin EP-1 was chosen. The EP-1 samples prepared in the form of type 1B (dumbbell) and type 2 (strip) specimens were tested in uniaxial tensile test at temperature 20 °C and deformation rate 5 mm/min. The mean values of tensile strength, elongation and modulus of elasticity are presented in Fig. 4.

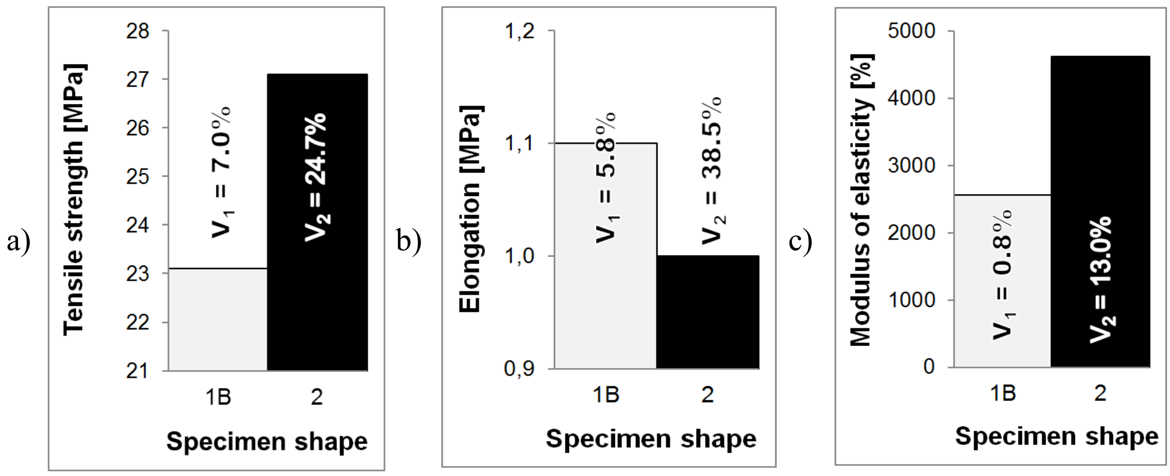


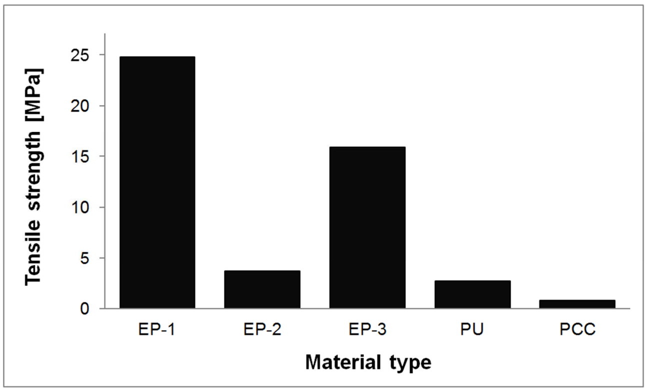
Figure 4: Influence of specimen geometry on tensile strength (a), elongation (b) and modulus of elasticity (c) of EP-1 material with coefficient of variation V (test parameters – temperature 20 °C, deformation rate 5mm/min)

All measured mechanical parameters are greatly affected by specimen shape. The dispersion of results received for strip specimens in comparison with dumbbell specimens are ~3.5 and ~16 times greater for the tensile strength and the modulus of elasticity respectively. The high dispersion of results for strap specimens could be caused by preparation procedure (cutting strips from coating according to EN ISO 527-3:1998) that may introduce some microcracks into edges of type 2 samples, and in the consequence higher stress concentrations and higher variation of the results. It confirmed that dumbbell samples give more reliable results and they should be used for tensile testing of polymer repair materials, if it is possible.

Despite results mentioned above, the sample shape chosen to investigate the influence of material type and deformation rate was type 2 with thicknesses closer to those after material application. Moreover, in case of some materials preparation of dumbbell specimens is difficult due to curing process e.g. water-borne coating EP-2.

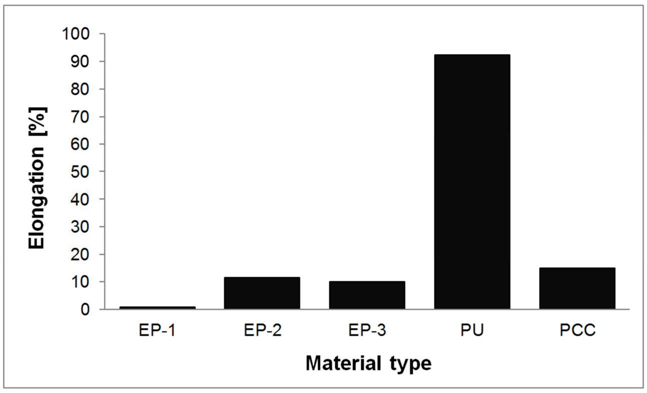
Effect of material type. The investigation of the material type effect was conducted for EP-1, EP-2, EP-3, PU and PCC. The same test parameters: temperature 20°C and deformation rate 50 mm/min was used for all samples of type 2. The results obtained in the study confirmed that mechanical properties of repair materials are dependent on the type of material, and in fact on the chemical composition (Fig. 5).

a)



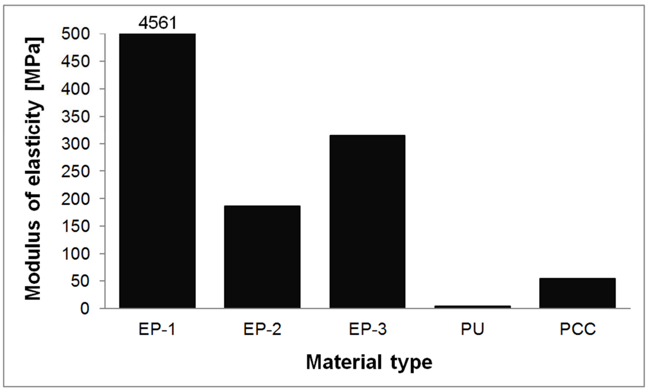
CV [%]	
EP-1	11.8
EP-2	13.0
EP-3	20.4
PU	4.1
PCC	20.1

b)



CV [%]	
EP-1	16.3
EP-2	22.5
EP-3	1.0
PU	4.8
PCC	8.3

c)



CV [%]	
EP-1	6.0
EP-2	32.0
EP-3	53.1
PU	1.9
PCC	19.4

Figure 5: Influence of material type on: a) tensile strength, b) elongation and c) modulus of elasticity for EP-1, EP-2, EP-3, PU and PCC material and corresponding coefficients of variation CV (test parameters: temperature 20°C, deformation rate 50 mm/min)

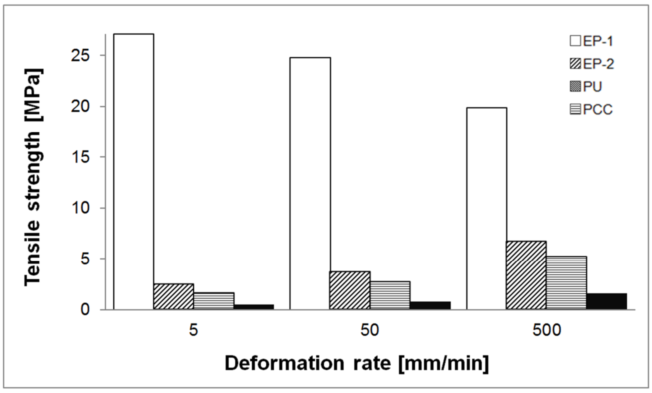
The highest tensile strength is exhibited by injection material (EP-1) – 25 MPa and lower for coating materials - the lowest one for PCC – 1 MPa. The elongation is diversified, it equals 92% for PU, 12% for EP-2, 15% for PCC and only 1% for EP-1. EP-1 shows modulus of elasticity of 4560

MPa, much lower value were observed in case of coating materials: EP-3, EP-2, PCC and PU – 315 MPa, 186 MPa, 55 MPa and 4 MPa respectively.

The coefficient of variation differs significantly, especially in case of EP-3. Its value ranges from 1% (elongation) to 53% (modulus of elasticity). The lowest dispersion was observed for PU – 4.1% for tensile strength, 4.8% for elongation and 1.9% for modulus of elasticity. The results obtained in the study confirmed variation of mechanical properties for various coating materials depend on their chemical composition. Therefore, to test effect of deformation rate three types of materials were selected: resin for crack injection (EP-1), water-born epoxy coating EP-2, elastic coating PU and polymer-cement protective coating (PCC).

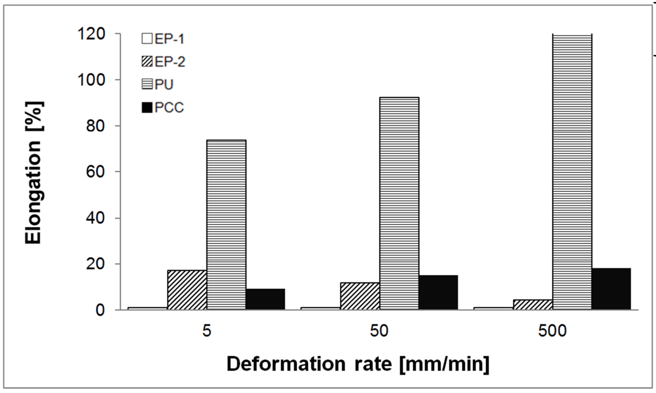
Effect of deformation rate. The relationship between deformation rate of 5, 50, 500 mm/min and mechanical properties of EP-1, EP-2, PU and PCC were examined using samples of type 2 at temperature 20 °C. The thicknesses of coatings corresponded to those recommended for application.

a)



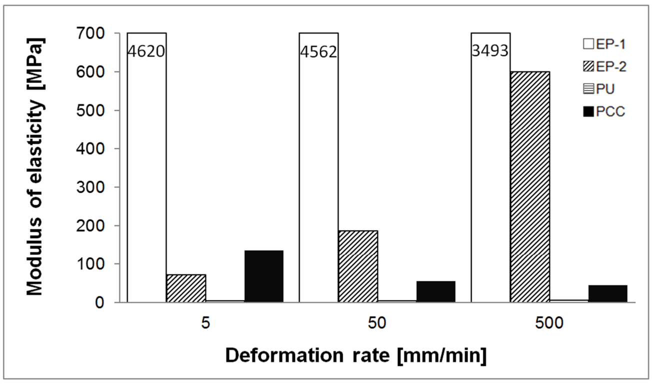
CV [%]			
Material	5 mm/min	50 mm/min	500 mm/min
EP-1	24.7	11.8	10.3
EP-2	29.6	13.0	5.1
PU	16.4	4.1	7.7
PCC	49.1	20.1	24.1

b)



CV [%]			
Material	5 mm/min	50 mm/min	500 mm/min
EP-1	38.5	16.3	45.0
EP-2	10.6	22.5	31.3
PU	20.1	4.8	6.6
PCC	26.1	8.3	44.5

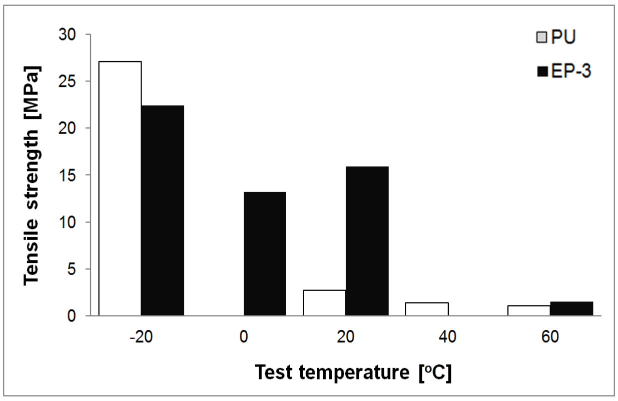
c)



CV [%]			
Material	5 mm/min	50 mm/min	500 mm/min
EP-1	13.0	6.0	19
EP-2	10.0	32.0	-
PU	3.4	1.9	1.7
PCC	23.4	19.4	27.9

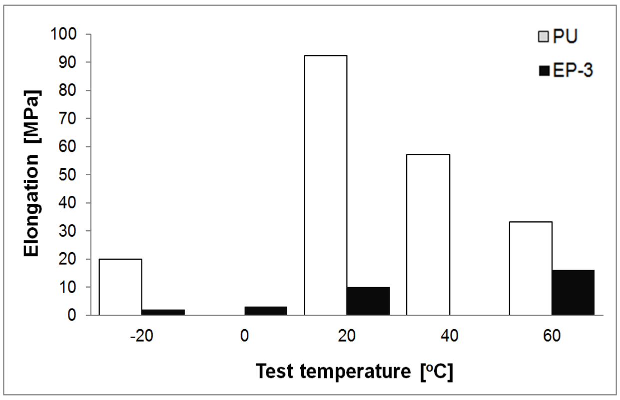
Figure 6: Influence of deformation rate on: a) tensile strength, b) elongation and c) modulus of elasticity for EP-1, EP-2, PU and PCC materials and corresponding coefficients of variation CV (test parameters: temperature 20 °C, deformation rate 5, 50 and 500 mm/min)

a)



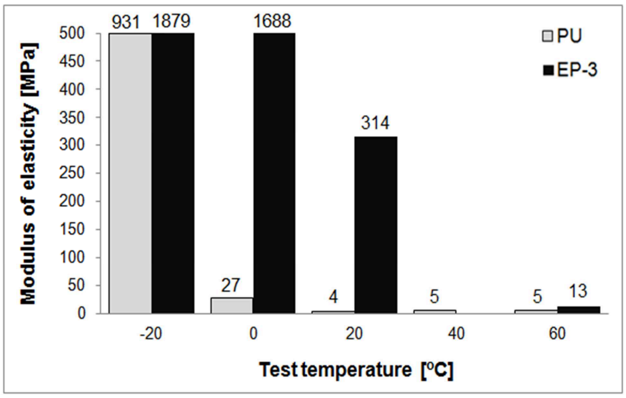
	CV [%]	
Temp.	PU	EP-3
-20°C	7.1	3.2
0°C	-	33.6
20°C	4.1	20.4
40°C	3.3	-
60°C	31.2	22.2

b)



	CV [%]	
Temp.	PU	EP-3
-20°C	51.4	33.4
0°C	-	35.4
20°C	4.8	1.0
40°C	15.0	-
60°C	4.2	4.4

c)



	CV [%]	
Temp.	PU	EP-3
-20°C	0.4	4.9
0°C	11.7	6.0
20°C	1.9	53.1
40°C	15.6	-
60°C	11.4	4.5

Figure 7: Influence of test temperature on: a) tensile strength, b) elongation and c) modulus of elasticity for PU and EP-3 coating and corresponding coefficients of variation CV (test parameters: temperature -20, 0, 20, 40 and 60 °C, deformation rate 50 mm/min)

The influence of deformation rate is different depending on material type (Fig. 6). Injection material EP-1 shows unexpected behavior – the decrease in tensile strength, modulus of elasticity and almost constant elongation with increasing of deformation rate. The deformation rate in the case of EP-2 and PCC has similar impact - the greater the rate, the higher tensile strength, modulus of elasticity and lower elongation. Increase of deformation rate results in an increase of tensile strength, elongation and negligible increase of modulus of elasticity.

The deformation rate has also impact on coefficient of variation. Minimal variation of results of tensile strength for EP-1, EP-2 were achieved at 500 mm/min. PCC as well as PU first demonstrate decrease at rate 50 mm/min and then increase of coefficient of variation at rate 500 mm/min. The same effect is observed in case of elongation for EP-1, PU and PCC samples. EP-2 results demonstrate continuous increase of dispersion with increase of deformation rate. Dispersion of modulus of elasticity obtained for EP-1 and PCC decreases and then increases with increase of deformation rate. The coefficient of dispersion for EP-2 and PU results increases and decreases respectively, when the rate increases. It was concluded that the most suitable deformation rate for coating materials is 50 mm/min. The EP-1 results are not in agreement with common behavior, and that is probably because EP-1 was not hardened enough. It was confirmed in testing of mechanical properties of EP-1 after conditioning at 80°C. The observed changes were similar to those reported commonly for this type of resins – tensile strength as well as modulus of elasticity increased and elongation decreased with increasing of deformation rate.

Effect of temperature test. The EP-3 and PU coatings, as coatings more susceptible to elevated temperatures during service, have been selected for testing. The tests were carried out at temperature: -20, 0, 20, 40 and 60 °C in special chamber. To avoid the shape effect described earlier, the samples of 1B type were used for the test. In the previous chapter the deformation rate of 50 mm/min was found to be the most appropriate for tensile testing of polymers, therefore it was chosen for the experiment.

The results obtained indicate that test temperature does not have the same influence on EP-3 and PU. As shown in Fig. 7. PU samples exhibit decrease of tensile strength and modulus of elasticity with increase of temperature. Elongation first increases up to 20 °C and then decrease when temperature exceeds this value. Changes of tensile strength and modulus of elasticity of EP-3 floor are similar, but less obvious than PU. One difference between both materials is that EP-3 and PU reveal maximal elongation in different temperatures: – 20 °C and 60 °C respectively. The results for PU demonstrate the lowest variation at its operating temperature – 20 °C. Due to equipment limitations (too small chamber sizes) tensile test of PU samples at 0 °C was not finished.

Conclusions

The obtained results of systematic investigation presented in this paper confirmed that selection of tensile test parameters is critical in the evaluation of mechanical properties of polymer and polymer coatings. All mechanical parameters determined in uniaxial tensile test, as well as their dispersions, are clearly affected by specimen shape, material type (chemical composition), deformation rate and temperature. The test results confirmed the need to identify specific parameter values applied to tensile test to determine the mechanical properties of the coatings. For example, dumbbell samples give results with lower dispersion and they should be used for tensile testing of polymer repair materials, if it is possible. In the case of necessity of testing of strip specimens higher dispersion of results should be expected. The results indicate that the most suitable deformation rate for coating materials is 50 mm/min in this case. Similar approach was used for testing polymer and polymer-cement mortars and concretes elaborated by RILEM TC 1013 [13].

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