pends on environmental conditions during application of material and service of repaired construction.

As already indicated, the CI curves can be used to compare the compatibility of different concrete mixtures and to identify specific material tendencies. In a recent investigation by Modjabi-Sangnier [7], test results show that a given binder/plasticizer agent combination can yield quite different conclusions depending on the curing temperatures. While some combinations exhibit more interesting characteristics at low curing temperatures with respect to compatibility and the cracking risk, others show exactly the opposite, as observed in the example provided on the graph of Figure 3.

Compatibility modeling approach

In comparison with cement-based repair materials, polymer-based materials are much more sensitive to temperature, both at the time of application and during their service life, owing to their typically much larger coefficient of thermal expansion. Application guidelines and requirements are usually well described in technical data sheets. While the properties and characteristics presented in the latter are generally determined at room temperature, they can actually vary considerably with the ambient temperature fluctuations.

An example of such is provided in Figure 4, which shows results of direct tensile tests experiments conducted on two commercial polymer coatings (epoxy EP and polyurethane PU) intended for industrial flooring use [9]. The experiments were carried out at different temperatures (-20; 0; 20; 40 and 60 °C) using a testing machine equipped with a thermal conditioning chamber. The experiment results clearly show that temperature does not exertthe same influence on epoxyand polyurethane.

To analyze quantitatively the effect of temperature upon compatibility of polymer-based repair systems, a modeling approach proposed by Czarnecki et al. [2] was used. They have proposed three main compatibility models for injection materials, patch repairs and protective coatings respectively. Each model consists of a series of equations defining specific compatibility requirements to be

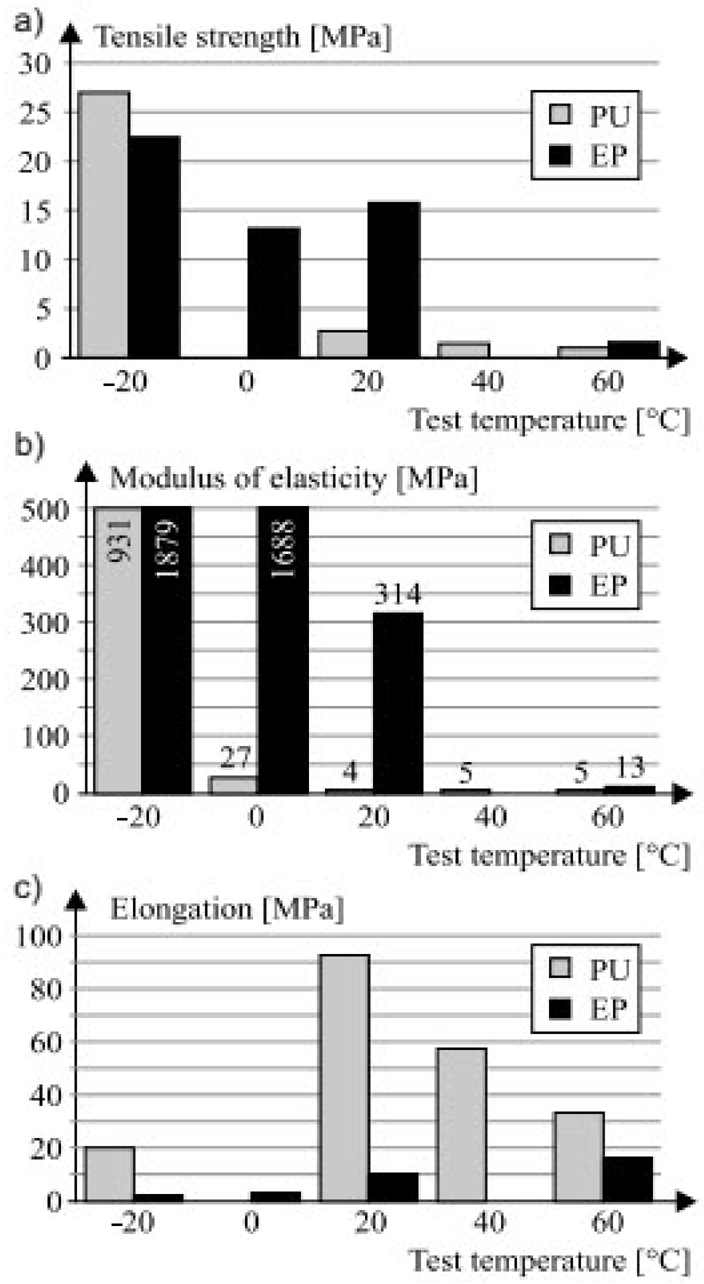

Fig. 4. Influence of ambient temperature upon: a) tensile strength; b) modulus of elasticity, and c) elongation for polyurethane-based (PU) and epoxy-based (EP) coatings deformation rate of 50 mm/min) – acc. to [9]

Rys. 4. Wpływ temperatury podczas badania na: a) wytrzymałość na rozciąganie; b) moduł sprężystości; c) wydłużenie przy zerwaniu powłoki poliuretanowej (PU) i epoksydowej (EP); prędkość odkształcania 50 mm/min – wg [9]

fulfilled for selected repair systems. The variables in the formulas are measurable material properties. Based upon these formulas, a N-dimensional compatibility space can be created. To determine such compatibility space, where all requirements are fulfilled, suitable computer tools were developed [5, 6]. They allow for graphical presentation of 3D compatibility subspaces defined by selected material properties.

Figure 5 presents the examples of compatibility subspaces determined for the two aforementioned polymer-based coating applied on a concrete substrate having the same concrete substrate characteristics, i.e. mechanical and thermal properties, crack width and temperature gradient. The calculations were performed using the computer tool ANCOMP developed at Warsaw University of Technology. To determine compatibility space at different service temperatures, the data yielded in direct tensile test were used in evaluating the specific compatibility requirements. Results of the simulations show that temperature changes in service can significantly affect the potential or ability of a given polymer-based repair material to fulfill the requirements for compatibility on a given concrete substrate because of the resulting changes in mechanical properties. The effect of thermal variations upon the respective properties of EP and PU coatings translated into significant differences in the calculated compatibility space ranges.

Conclusions

The proposed compatibility index appears as a quite promising analytical tool for predicting the performance of repair materials in terms of shrinkage-cracking resistance. Compatibility index data determined from individual material properties were found to be consistent with the experimental results yielded in ring tests.

Compatibility spaces show as another quite valuable tool for qualifying repair materials in view of dimensional compatibility. In addition to taking into account a wide range of prameters in the analysis, it allows to address the variability considerations (material properties, exposure conditions).

The complimentary compatibility approaches presented in this paper provide a sound basis for the identification of dimensional compatibility criteria. Such performance criteria are much awaited in the repair industry, to assist both the development of crack-resistant materials and the issuance of improved materials specifications.

References

[1] Czarnecki Lech, Alexander M. Vaysburd, N. P. Mailvaganam, P. H. Emmons, J. E. McDonald. 2000. „Repair and rehabilitation of structures – Some random thoughts". *Indian Concrete Journal* (74): 13 – 20.

[2] Czarnecki Lech, J. R. Clifton, Wiesława Głodkowska. 1992. „Problem of compatibility of polymer mortars and cement concrete system". *International Colloquium Materials and Restoration*. Esslingen: 964 – 971.

[3] Czarnecki Lech, Paweł Łukowski, Andrzej Garbacz. 2017. *Naprawa i ochrona konstrukcji z betonu. Komentarz do PN-EN 1504*. PWN.

[4] Emmons P. H., J. E. McDonald, Alexander M. Vaysburd. 1992. „Some compatibility pro-

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