By comparing the ring test results with the calculated tensile stresses, the validity and accuracy of the theoretical approach could be appraised.

Figure 2 shows an example of ring test results obtained for a self-compacting repair concrete mixture produced with a slag-based ternary binder (SCC-ST). On the diagram, the calculated theoretical stress evolution with and without stress relaxation (lower and upper solid red lines respectively) and the experimental stress recorded over time in the ring test (solid blue line) are presented together with the corresponding tensile strength evolution curve (black line).

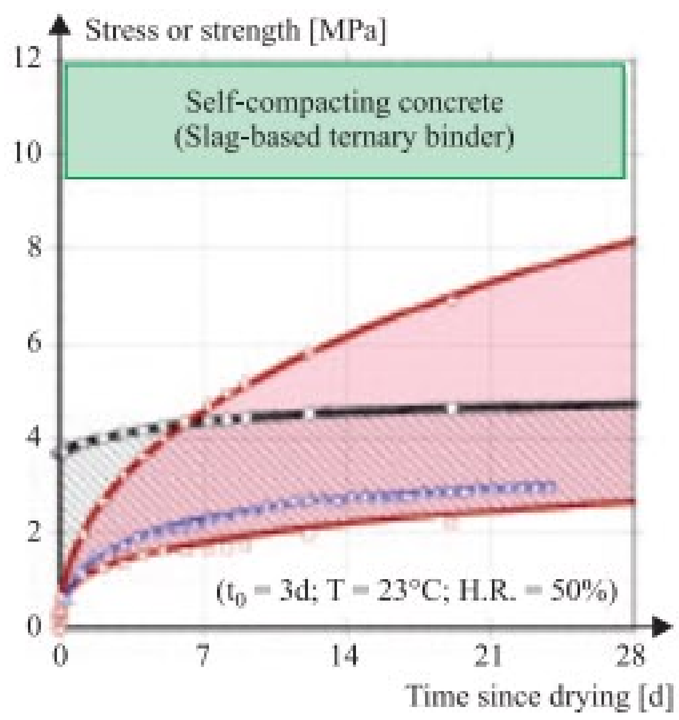

Fig. 2. Recorded and theoretical tensile stresses in AASHTO PP34 ring test specimens exposed to drying at 50% R. H. at the age of 3 days for a self-compacting concrete mixture made with slag-based ternary cement (note: solid blue line: stress recorded in the ring; lower and upper solid red lines: theoretical average concrete stress, with and without stress relaxation respectively; solid black line: tensile strength of the concrete) [7]

Rys. 2. Zarejestrowane i teoretyczne naprężenia próbki samozagęszczalnej mieszanki betonowej z cementem z żużlem, poddanej suszeniu przy względnej wilgotności RH=50% po 3 dniach wiązania, wyznaczone w teście pierścieniowym wg AASHTO PP34 (ciągła niebieska linia: naprężenie zarejestrowane w pierścieniu; dolna i górna czerwona linia: teoretyczne średnie naprężenia odpowiednio z i bez relaksacji; ciągła czarna linia: wytrzymałość betonu na rozciąganie) [7]

The pink areas between the red lines on the graph of Figure 2 correspond to the theoretical stress relaxation potential of the concrete. Overall, good correlation was found between the ring test results and the tensile stress values calculated based on individual concrete properties/phenomena, especially when taking into account stress relaxation. The level of correlation was found to increase when the test specimens (beams, rings) were partially sealed such as to obtain the same drying surface/volume ratio (S/V) in the various experiments. Based on the collected data and observations, it can be asserted that the calculation method that was developed provides a good basis for analyzing quantitatively the dimensional compatibility of repair materials.

Compatibility index calculation

Classical formulas derived for thick cylindrical specimens were used to analyze the tensile stress buildup in restrained shrinkage test specimens. A quantitative approach for the evaluation of concrete repair with a single dimensional compatibility parameter, the compatibility index, was then developed. Compatibility index evolution curves were finally calculated for a range of repair concrete mixtures in order to validate the approach and highlight material behavior relating to composition parameters and temperature. The dimensional *compatibility index* can be expressed in terms of deformation, thus allowing to relate explicitly to the various individual properties and phenomena involved in the material's response in restrained shrinkage conditions (strength, elastic modulus, creep, drying shrinkage), as well as to the degree of restriction of the element. For the latter, constants are calculated, based upon the respective geometry and mechanical properties (Poisson's ratio) of both the restraining device and the test specimen.

The time-dependent expression takes the following general form, where f_t is the concrete tensile strength, α_r is the instantaneous elastic degree of restraint, and α'_r is the creep-dependent restraint:

$$C.I.(t) = \frac{\left[\frac{f_t(t)}{E_c(t)} + \phi_c(t)\varepsilon_{fs}(t)\alpha_r(t)\frac{C_c}{C_g}\alpha'_r(t)\right]}{\varepsilon_{fs}(t)\alpha_r(t)} \quad (2)$$

$$C_g = \frac{b(b+c)}{c^2-b^2} \quad C_c = \frac{b^2+c^2}{c^2-b^2} - v_c \quad C_s = \frac{b^2+a^2}{b^2-a^2} + v_s$$

$$\alpha_r(t) = \frac{C_g}{\left(\frac{C_s}{E_s} + \frac{C_c}{E_c(t)}\right)E_c(t)}$$

$$\alpha'_r(t) = \frac{C_g}{\left(\frac{C_s}{E_s} + \frac{C_c(1+\phi_c(t))}{E_c(t)}\right)E_c(t)}$$

As it requires the evaluation of individual properties that for most are readily available (i.e. strength, elastic modulus, and drying shrinkage), the *compatibility index* carries much potential as a relatively simple and convenient analytical tool for assessing the cracking potential of concrete repair materials.

The CI parameter can alternatively be expressed in terms of stress. The compatibility index is then calculated as the ratio between the sum of the tensile strength (f_t) and total stress relaxation ($\Delta\sigma_{relaxation}$) in given restraining conditions, and the averaged elastic stress ($\sigma_{elastic}$) induced by restrained drying shrinkage.

The solid curve presented in the diagram of Figure 3 shows the evolution of this index at 23°C for the concrete mixture tested in the ring experiment (Fig. 2). Characteristically high at early age, the CI value is observed to decrease gradually with the ageing process, with quite steep decreasing rates in the first few days. The ring test stress development curve on the diagrams of Figure 2 show good agreement with the trends revealed by the CI curves. As a matter of fact, the rapid increase in tensile stress recorded for the SCC-ST rings is consistent with the steep decreasing rate of the CI value observed at 23 °C in the graph of Figure 3.

The compatibility between repair material and concrete substrate also de-

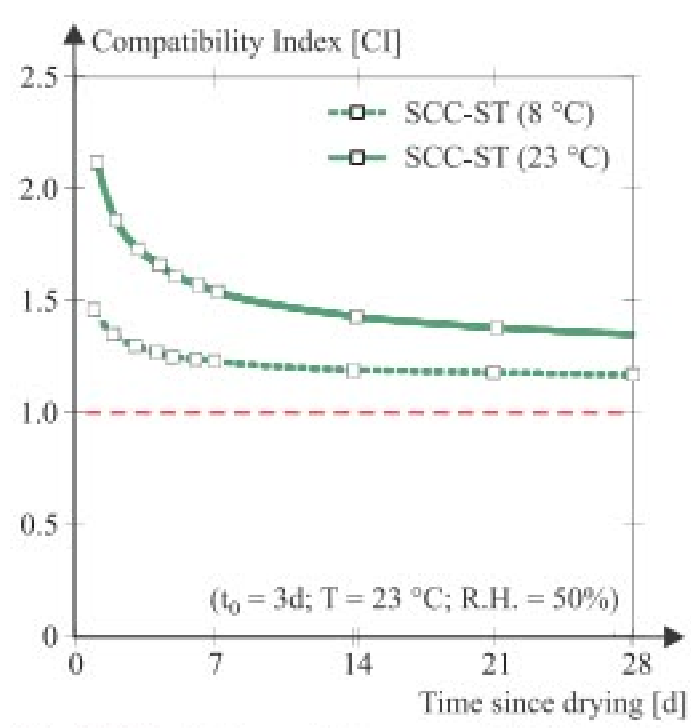

Fig. 3. Evolution of the compatibility index (CI value) with time calculated from ring test specimens exposed to drying at 50% R.H. at the age of 3 days, at different temperatures – self-compacting concrete mixture made with slag-based ternary cement [7]

Rys. 3. Zmiana wartości indeksu kompatybilności obliczona na podstawie wyników testu pierścieniowego próbki samozagęszczalnej mieszanki betonowej z cementem z żużlem poddanej suszeniu przy względnej wilgotności RH=50%, w temperaturze 8 i 23 °C, po 3 dniach wiązania [7]