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PARAMETERS OF INTERFACE BETWEEN SHRINKABLE AND EXPANSIVE CONCRETE RESULTING FROM THEIR ADHESION

Anna Halicka
Lublin University of Technology, Lublin, Poland

ABSTRACT

Two aspects of static work of the joint between shrinkable and expansive concrete, resulting from the specific nature of the adhesion of expansive concrete, are discussed. Firstly, the effectiveness of the joint between shrinkable and expansive concrete working in different stress-strain states was tested. It was stated that the strength of such a joint is greater than in the case of the connection of two shrinkable concretes. Secondly, it was considered that expansion occurs in the young expansive concrete while the adhesion is still in process and the interface is deformable. On the basis of the layer structures' mechanics the influence of interface deformability on the initial stress-strain state, caused by expansion in concrete composite structures, was confirmed. The stresses caused in the interface by expansion are lower at the end of the composite beam or plate than in the case of a non-deformable interface, but they appear on the longer section of the beam. The final value of the force of expansion, causing the 'prestressing' of an element, changes along the composite beam or plate according to the level of interface deformability.

Key words: composite concrete structures, expansive concrete, adhesion, interface, bond strength, deformability of interface

INTRODUCTION

The problem of joint and co-operation of two different concretes appears in many real situations, for instance:

- in technological breaks which are inevitable while placing concrete in structures of considerable dimensions,
- in structures composed of precast elements jointed by cast in-situ concrete,
- in concrete composite elements, where the cross-section is composed of a precast element and cast in-situ concrete,
- in repairs of concrete structures realised by encasement or placing new layers of concrete.

A properly constructed joint should ensure co-operation of the connected parts while bearing loads. Such co-operation is possible owing to adhesion.

The adhesion is usually defined as all physico-chemical phenomena occurring in the interface of two bodies being in contact and resulting in their attachment to each other. There are a lot of theories explaining the nature of adhesion by presence of different causative agents [16, 20]. In general these agents are divided into two groups: mechanical interlocking and specific adhesion. The first phenomenon consists in penetrating of the pores and surface roughness of the connected elements by an adhesive. This means increasing the real contact area and, after the hardening of the adhesive, mechanical interlocking. Among the theories describing specific adhesion one can distinguish: electrostatic theory, diffusion theory, theories based on adsorption resulting from chemical bond, interactions through electron pair sharing, van der Waals interactions and the theory of weak boundary layer.

Connection of concretes (so-called 'old' and 'new' ones) is a special case of the system described above, where the grout of the 'new' concrete performs the duty of the adhesive, so that the connected elements and the adhesive are identical in chemical respect.

It seams then that intermolecular forces are of great importance for occurrence of adhesion while placing 'new' concrete, because they enable the grout to penetrate into pores and roughen the 'old' concrete surface. Next, during the setting of the 'new' concrete, chemical reactions may occur between 'new' grout and non-hydrated particles of cement in the 'old' concrete. Thus the chemical adhesion takes part. After hardening, the 'new' grout filling the roughness of the 'old' concrete causes the effect of mechanical interlocking.

More and more often now, especially in repairs, a connecting layer on the 'old' concrete surface is used. Primers are predominatingly grouts with resin additives, which activate the specific adhesion. Thus it is a case approximating the classical process of gluing.

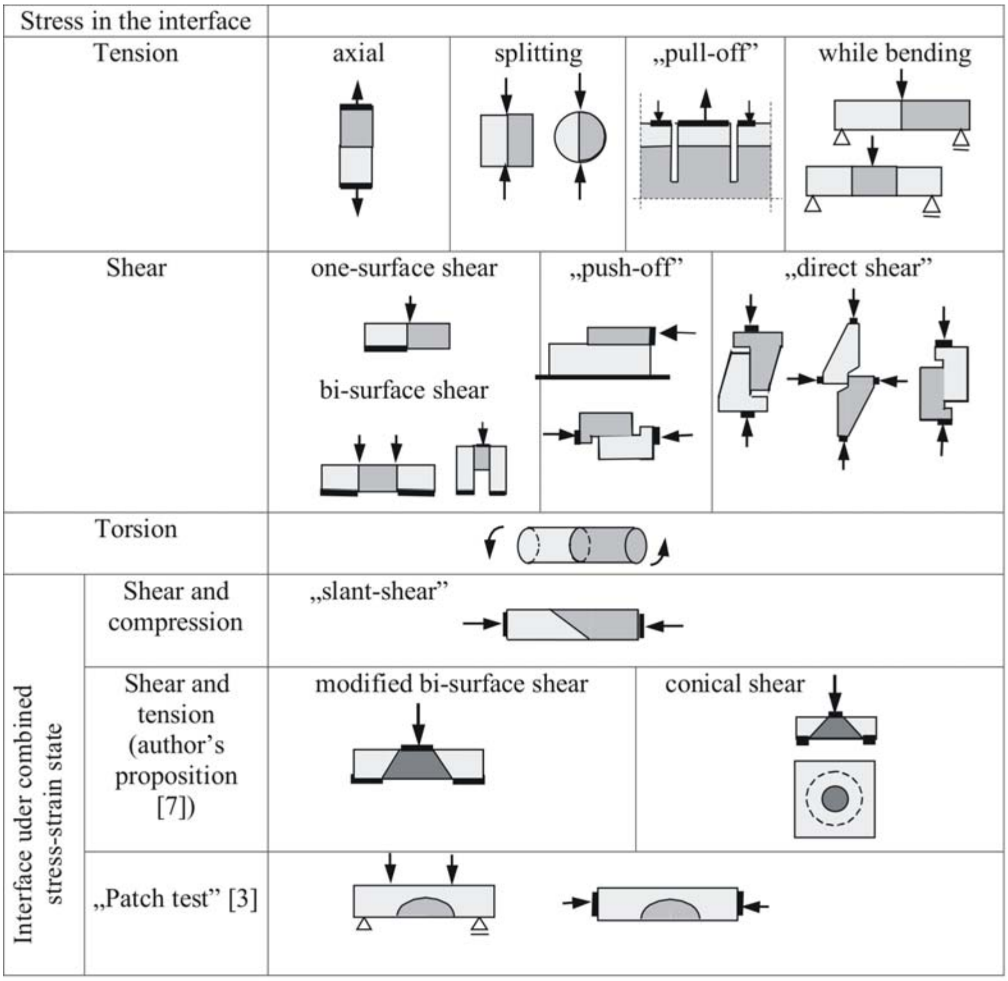
The measure of adhesion is specified by bond strength, which may be tested and estimated. In concrete composite structures the interface between two concretes works in different stress-strain states: under compression, tension, shear, torsion or combination of normal and shear stresses. Thus is no single universal bond strength of concretes, but bond strength must be related to defined stress-strain state in the interface. Table 1 complies the types of specimens usually used for testing of bond strength between two concretes. It also contains the 'modified bi-surface shear' specimen and 'conical shear' specimen, both designed by author [7]. The interface works in these specimens in combined stress state of shear and tension.

The results of investigations of specimens with the interface working in different stress-strain state (e.g. [2, 3, 4, 5, 14, 17, 19]) are characterised by a wide spread of values. In most tests, however, independently of the interface stress-strain state, one can notice that the surface obtained by the vibration of 'old' concrete without additional treatment and the surface obtained by splitting the original specimen are characterised by considerable bond strength. Surface roughening only slightly improved the bond strength and in some cases made it even worse. For instance the needle-gunning of the surface caused a reduction of bond strength, better results were obtained after wire-brushing and hand-chiselling.

It can be stated then that even a visually smooth concrete surface (except the surface cast against steel mould) is rough enough, after removing dirt and cement wash, for ensuring good adhesion. On the other hand, roughening may damage the structure of the upper layer of 'old' concrete, weakening the joint.

Thus a sensible activity while searching for new methods leading to high bond strength of two concretes is not developing new ways of surface treatment, but ensuring better specific adhesion. This may be achieved for instance by using primers compounded with resin. Another way may be the utilization of expansive concrete as 'new' concrete.

Table 1. Specimens for testing the bond strength of two concretes



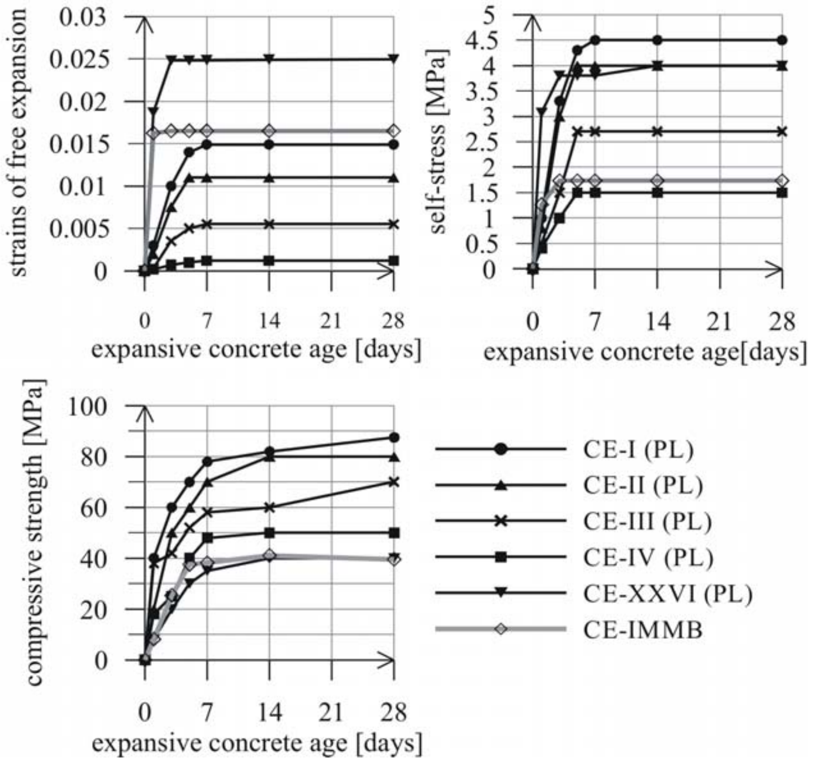
CHARACTERISTIC OF EXPANSIVE CONCRETE

Concretes made with expansive cement binders belong to the group of special concretes. Their special feature is an increase in volume during setting and curing. A distinction is made between shrinkage-compensating concretes, in which little strains of free expansion (up to ~0.1%) only compensate the shrinkage which takes place, and expansive concretes, i.e. those with greater strains. The value of free expansion of concrete depends on the type and quantity of the binder used, as well as the amount and characteristics of the aggregate and the technological factors.

The most frequent among expansive cement binders are those in which the reactions of aluminosulfate compounds are used, leading to the formation of ettringite. Since the increase in volume is the result of the growth of ettringite crystals, the character of the expansion may be described as structure-forming and hard phase building. It occurs first of all 'inwards', filling the available pore space, and only then 'outwards'. The physico-chemistry of expansive cements, as well as the theories describing the mechanism of the expansion and the procedures of expansive cement production, are presented in references [11, 13, 16].

The basic feature characterising binder expansion is the free linear strain of a cuboid specimen not confined during its curing by any external constrains. If the expansion takes place in confined freedom conditions, then smaller, so-called non-free, strains will occur, while self-stresses are generated in the specimen. The two parameters mentioned above are the measures of the energoactivity of expansive cement. They are examined in a standardised manner, described in reference [11], on the specimens made of expansive mortar. Fig. 1 presents the characteristics of expansive binders produced in Poland in the Institute of Mineral Building Materials in Cracow (IMMB) and the Lublin University of Technology (PL).

Fig. 1. The characteristics of expansive cements produced in Poland (author's tests): a) free expansion, b) self-stresses, c) compression strength



Apart from expansive cements, more and more often additions to shrinkable cement are used, increasing the volume of the grout, mixed with cement usually at the stage of mortar or concrete mix making. It seems that for practical reasons these additions will find the broadest application.

In structural elements made of expansive concrete, due to the confinement of the freedom of expansion by internal constraints (structure, reinforcement) as well as external ones (abutments, supports, adjacent structural elements), internal stresses (so-called self-stresses) do occur. The stresses are also generated in adjacent parts of the structure.

As it was mentioned above, an increase in the volume of materials based on mineral expansive binders is the result of the growth of ettringite crystals. In the case of repair the ettringite crystals are also built in the interfacial zone, filling roughness of 'old' concrete surface and penetrating open pores. This means that the effectiveness of both kinds of bond mechanisms, mechanical interlocking and specific adhesion, will grow. Additionally, the expansion suppresses the possibility of shrinkage cracking in the interface and increases the bond strength.

TESTING THE BOND STRENGTH BETWEEN EXPANSIVE AND SHRINKABLE CONCRETE

In order to quantitatively evaluate the adhesion between expansive and shrinkable concrete a number of tests were carried out by the author. The bond strength of the interfaces working under different stress-strain states was tested. Each test was earlier presented in detail. In particular, there were:

- tests of tensile bond strength realised by splitting [6],
- tests of axial tensile bond strength [8],
- tests of bond strength of the joint shaped as the cylindrical surface [10],
- tests carried out using the 'modified bi-surface shear' specimens [7],
- tests carried out using the 'conical shear' specimens [7],
- 'slant-shear test' with the joint working in a combined stress state of shear and compression [6].

All specimens were made in two stages. First the 'old' concrete was placed into mould and the remaining space was filled by foamed polystyrene. After 28 days of curing the surface of the concrete was moistened and roughened by wire-brushes and the specimen was complemented by 'new' concrete'. Tests were executed after the next 28 days in a hydraulic testing machine.

Table 2 presents the results of the tests, as a mean values of three specimens. The compressive f_{cm} and tensile strength f_{ctm} of 'old' and 'new' concretes determined at the day of the main tests, the value of the destroying forces and the calculated values of the destroying stress were compiled here. The characterisation of the 'new' concrete was complemented by the information whether the freedom of strains was confined during its curing. As the main parameter enabling the appreciation of bond strength and comparison of results the coefficient of joint effectiveness was adopted. It was defined as follows:

$$\alpha_z = \frac{f_z}{f_{\min}} \tag{1}$$

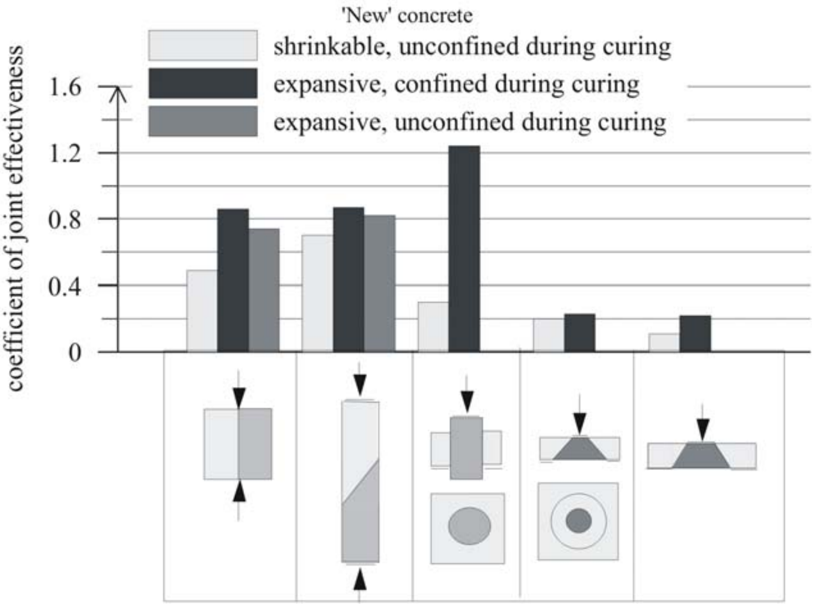
where:
f_z – bond strength (value of stress destroying the specimen),
f_{min} – strength of the weaker of connected concretes, tested in the same stress-strain state as composite specimen.

Table 2. Results of tests of concrete composite specimens with interface working in different stress-strain state

Test	'New' concrete; confinement of strains during curing	Strength of 'old' concrete [MPa]		Strength of 'new' concrete [MPa]		Destroying force [kN]	Destroying stress [MPa]	Coefficient of joint effectiveness α_z	Percent of joint damage
		f_{cm}	f_{ctm}	f_{cm}	f_{ctm}				
Splitting	Shrinkable. free	28.81	2.22	29.03	2.20	38.5	σ_{jt} =1.09	$\frac{\sigma_{jt}}{f_{ctm}} = 0.49$	100%
	Expansive. free	28.81	2.22	29.80	2.32	59.0	σ_{jt} =1.65	$\frac{\sigma_{jt}}{f_{ctm}} = 0.74$	33%
	expansive. confined	28.81	2.22	44.51	3.50	68.67	σ_{jt} =1.92	$\frac{\sigma_{jt}}{f_{ctm}} = 0.86$	100%
Slant-shear test	Shrinkable. free	27.07	2.11	27.64	2.30	188.3	σ_j =18.8	$\frac{\sigma_j}{f_{cm}} = 0.70$	100%
	Shrinkable. confined	26.83	2.56	27.40	2.15	220.0	σ_j =22.0	$\frac{\sigma_j}{f_{cm}} = 0.82$	100%
	Expansive. free	27.01	2.11	40.20	3.01	222.5	σ_j =22.2	$\frac{\sigma_j}{f_{cm}} = 0.82$	0
	Expansive. confined	26.83	2.56	41.36	3.59	235.0	σ_j =23.5	$\frac{\sigma_j}{f_{cm}} = 0.87$	33%
Axial tension	Expansive. confined	18.6	1.96	39.6	2.48	10.13	σ_{jt} =11.8	$\frac{\sigma_{jt}}{f_{ctm}} = 0.95$	100%
Cylindrical shear	Shrinkable. free	41.83	3.10	38.49	2.91	100.67	τ_j =1.62	$\frac{\tau_j}{f_{cw}} = 0.30$	100%
	Expansive. free	41.83	3.10	50.33	3.62	430.48	τ_j =7.08	$\frac{\tau_j}{f_{cw}} = 1.24$	100%
Conical shear	Expansive. free	38.40	2.92	34.50	2.66	51.0	σ_{jt} = 0.52 τ_j = 0.78	$\frac{\sigma_{jt}}{f_{ctm}} = 0.195$	100%
	Expansive. confined	38.40	2.92	48.75	3.50	65.67	σ_{jt} = 0.67 τ_j = 1.00	$\frac{\sigma_{jt}}{f_{ctm}} = 0.23$	100%
Modified bi-surface shear	Shrinkable. free	39.03	2.76	36.84	2.47	12.5	σ_{jt} = 0.27 τ_j = 0.47	$\frac{\sigma_{jt}}{f_{ctm}} = 0.11$	100%
	Expansive. free	25.97	1.27	36.33	2.45	13.0	σ_{jt} = 0.28 τ_j = 0.49	$\frac{\sigma_{jt}}{f_{ctm}} = 0.22$	100%

Thus for each type of specimens the coefficient fixes the ratio of different stresses (normal or shear). The tests results were also illustrated on Fig. 2.

Fig. 2. Effectiveness of joint between two concretes working in different stress-strain state



The effectiveness of split connection between shrinkable concrete and expansive one, defined as a ratio of the stress destroying the composite specimen and the tensile strength of the weaker concrete, was over 50% higher in the case of concretes unconfined during curing than the connection of two shrinkable concretes. When the freedom of expansion was confined, this effectiveness was higher about 75%.

In a 'slant-shear' test, beside the increase of the ratio of destroying stress to the compressive strength of the weaker concrete, a change of the manner of destruction was observed. The specimens made of two shrinkable concretes were destroyed in the interface, whereas most of the specimens with one half made of expansive concrete were destroyed as monolithic specimens.

In the specimens with the interface shaped as a cylinder the effect of shrinkage or expansion was exposed. It was stated that the strength of such a joint, if the pushed cylinder was made of expansive concrete, was even four times higher than in the case of a shrinkable concrete cylinder. It should be noticed that in these investigations an expansive cement of high energoactivity was used (free expansion 1.65%, self-stress 4.0 MPa).

The increase of effectiveness of the joint between expansive and shrinkable concrete, in relation to the connection of two shrinkable concretes, was also observed while testing specimens with the interface working in combined stress-strain state of shear and tension, but it was considerable smaller (3÷11%).

Taking into consideration the fact that the joint between two concretes can by obtained by the utilization of the connecting layer, the effectiveness of use of expansive cement as a binder in primer was tested. The results of these tests were presented in detail in [8]. These tests consisted of the axial tension of the cylindrical specimens of two halves made of shrinkable concrete (obtained in initial investigations) connected by means of primer. Four series of tests were executed with different types of primer made of:

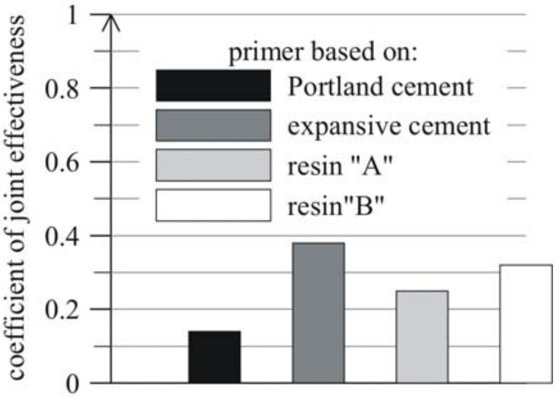
- Portland cement,
- expansive cement characterised by free expansion 0.16%,
- Portland cement with addition of a resin material based on styrol butadiene (A),
- Portland cement with addition of a resin material based on vinyl propionate (B).

Table 3. Test results of axially tensioned joint between two concretes realized by a connecting layer

	Connecting layer	Tensile strength of connected concretes, $f_{ct,p}$ [MPa]	Destroying force F_j [kN]	Strength of joint f_j [MPa]	Effectiveness of connection $\frac{f_j}{f_{ct,p}}$
1	Portland cement grout	1.92	1.37	0.27	14%
2	Expansive cement grout	1.92	3.81	0.76	39%
3	Grout with additive A	1.92	2.40	0.48	25%
4	Grout with additive B	1.92	3.13	0.62	32%

The results of the tests are presented in Table 3. The following values are compiled there: mean value of destroying forces, tensile bond strength calculated on the basis of these forces and the effectiveness of connection, defined as the ratio of such strength and the tensile strength of the concrete used to prepare the connected halves of specimens. Test results are also illustrated in Fig. 3. It was proved that the expansive cement grout is the most effective connecting layer – the effectiveness of connection was 39%. The effectiveness of grouts made by utilisation of materials A and B were respectively 25% and 32%. The weakest connecting layer was obtained when shrinkable cement grout was used (effectiveness 14%).

Fig. 3. The effectiveness of an axially tensioned joint between two concretes realized by means of a connecting layer



The above-described author’s tests of bond strength of two concretes with their interface working in different stress-strain states confirmed the assumption, that the adhesion of concrete based on expansive cement is more effective than that of concretes based on shrinkable cement. Effectiveness of this joint was especially high if the expansive concrete had optimal conditions for generation of self-stresses during curing (the freedom of strains was confined).

Obtained effectiveness values were compared by calculating the ratio of the effectiveness coefficient of the joint between expansive and shrinkable concrete to the corresponding coefficient of the joint between two shrinkable concretes. Such calculated ratios are presented in Table 4. It should be emphasised that joint effectiveness depends on the energoactivity of the expansive cement used. Thus in Table 4 the values of the free expansion strain of expansive cement are also given. Expansive cement characterised by bigger free expansion caused higher bond strength than cement of lower energoactivity.

Table 4. The compilation of tests results

Type of test	Strains of free expansion	The ratio of coefficient of effectiveness of joint between expansive concrete and shrinkable one to coefficient of effectiveness of joint between two shrinkable concretes
Splitting	0.005 (low level of expansion)	1.76
'Slant-shear test'	0.0024 (shrinkage-compensation)	1.24
Cylindrical shear	0.0165 (high level of expansion)	4.13
Conical shear	0.0014 (shrinkage compensation)	1.17
Modified bi-surface shear	0.005 (low level of expansion)	2.0
Axial tension (specimen with primer)	0.0019 (shrinkage compansation)	2.78

Finally, on the base of the author's tests, the following rule can be recommended. The bond strength of a non-reinforced joint between expansive and shrinkable concrete can be safely calculated as the value for porland concretes according to code EC2 [1] (product of coefficient characterising the roughness of surface and tensile strength of weaker concrete) multiplied by 1,1 in the case of shrinkage-compensating concrete and by 1,5 for expansive concrete.

THE INFLUENCE OF INTERFACE PARAMETERS ON THE VALUES OF INTERNAL FORCES IN A COMPOSITE ELEMENT WITH EXPANSIVE CONCRETE

Initial stress-strain state in composite cross-section caused by expansion

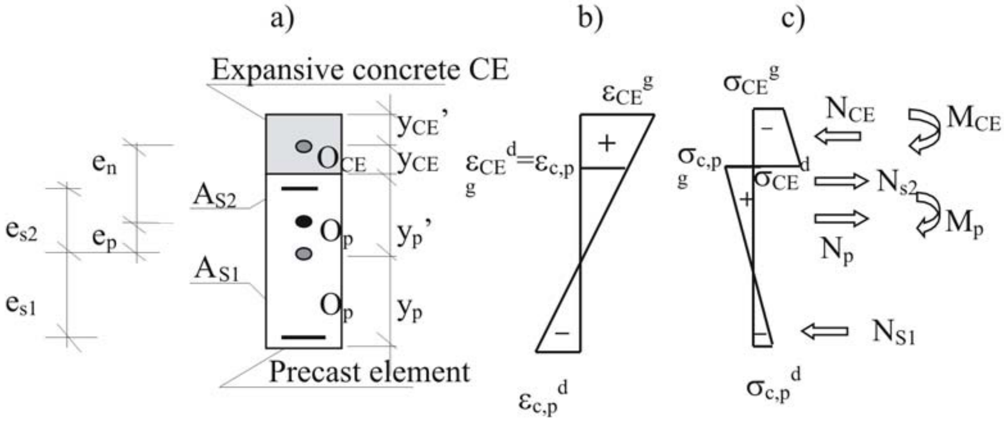
The examples of utilisation of expansive concrete in structures are the following [11]: cylindrical precast tanks prestressed by expansive concrete, self-stressed jointless pavements and floors, composite beams and slabs and concrete members repaired or strengthened by placing a layer of expansive concrete.

Further considerations refer only to composite concrete elements, where expansive concrete is used as cast in-situ concrete placed on the precast element. The basic idea of designing such elements is to take advantage of the initial stress-strain state. This state is caused by self-stresses generated during curing of expansive concrete and results in 'prestressing' of the precast element, though the level of stresses is usually low. The adhesion existing in the interface plays an important role in the distribution of initial internal forces between connected concrete parts.

The initial stress-strain state in the cross-section of a composite element due to expansion of cast in-situ concrete is presented in Figure 4. The distribution of forces and strains is analogical to the stress-strain state caused by shrinkage of cast in-situ concrete, but the directions of forces are reverse. It is advantageous to the static work of the element (in contrast to distribution caused by shrinkage), because in the zones where the external load causes tensile stress the initial compressive stress exists.

The peculiarity of composite structures with expansive concrete is the fact that it is not only self-stresses that influence the internal forces generated in the precast element but a kind of 'feedback' takes place here as well. The precast element, and especially its stiffness, influences the value of self-stresses generated and the effective value of expansion force N_{CE} (see Figure 4): the stiffer the precast element, the smaller the strains and the greater the self-stresses. Tur [11, 18] worked out a method of calculating the value of N_{CE} by modelling the precast element as so called 'substitute reinforcement'. It is a fictitious reinforcement, whose area and situation ensure an identical distribution of stress in expansive concrete as that caused by precast element.

Figure 4. Initial stress-strain state in composite cross-section with expansive concrete, according to [11, 18]: a) scheme of cross-section, b) distribution of strain, c) distribution of stress



The influence of the deformability of the interface on the initial stress-strain state in the composite cross-section

Besides the stiffness of the precast element, another factor influencing the value of self-stress in the composite cross-section is the deformability of the interface. The measure of this deformability is specified as a modulus of the interface deformability. It may be defined as a coefficient of proportionality between shear stress in the interface τ and strain difference $\Delta\varepsilon$ of fibres near the interface of the parts connected, along the distance Δx:

$$k = \frac{\tau}{\Delta \varepsilon} \tag{2}$$

In study [9], on the basis of the results of investigations presented by different researchers, the author analysed the values of the moduli of interface deformability describing the connections of two concretes. These moduli are characterised by broad spread of values (4 000÷54 000 MPa). The upper values of this interval were obtain in tests, where the 'push off' specimen was loaded in parallel to the interface with a uniformly distributed load. In the other tests the shear force was applied at the end of the interface, which caused a disturbance of stress distribution and a diminishing of the ultimate force. In the composite beams the load is applied to the interface continuously, so it is reasonable in the analysis to use the upper values of the specified interval $k = \sim 50\ 000$ MPa.

Considerations in [9] concerned the interfaces between cured concretes, the elasticity modulus of which achieved their final value. On the other hand expansion occurs when the expansive concrete is not fully cured. As the value of the modulus of interface deformability is connected with the value of the concrete elasticity modulus, it is lower than in the case of cured concrete. The second factor causing the diminishing of the modulus of interface deformability may be the cracking or plasticization of the upper part of precast element during expansion.

In order to assess the influence of the interface deformability on the effective value of expansion force, the laws of the mechanics of layer structures may be used - especially the solution given by Kubik [12] for the case of applying constant force and moment along the beam. The expansion of the cast in-situ concrete can be treated as such a constant load and the initial values of internal forces due to expansion are the following:

$$\begin{aligned} N_{CE} &= \sigma_{CE} \cdot A_{CE} \\ M_{CE} &= N_{CE} \cdot w_{0,CE} \end{aligned} \tag{3}$$

where:

σ_{CE} – self-stresses caused by expansion of in-situ concrete calculated while considering the stiffness of the precast element according to rules presented in [11, 18],

A_{CE} – area of the cross-section of expansive concrete,

$w_{0,CE}$ – distance between the centre of gravity of expansive layer and the centre of gravity of whole cross-section.

Values of shear stress $\tau(x)$ in the interface in the distance x from the end of the beam and the total shear force $T(x)$ in the interface (defined as an integral of shear stress calculated from the end of the beam till x) are described in this case according to [12] by expressions:

$$\tau(x) = \frac{k \cdot D_{10}}{\lambda} \cdot \frac{\sinh[\lambda \cdot (x - l/2)]}{\cosh[\lambda \cdot l/2]} \tag{4}$$

$$T(x) = \frac{D_{10}}{D_{11}} \left(\frac{\cosh[\lambda(x - l/2)}{\cosh[\lambda \cdot l/2]} \right) - 1 \tag{5}$$

where:

$$D_{10} = -\frac{N_{CE}}{E_{CE} A_{CE}} + \frac{N_{CE}}{E_p A_p} + \frac{M_{CE} w_0}{\sum E_i J_i}$$

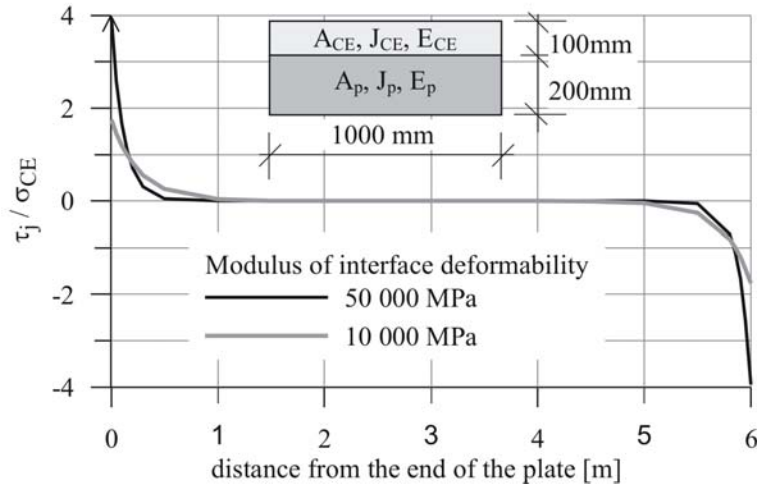
$$D_{11} = \frac{1}{E_{CE} A_{CE}} + \frac{1}{E_p A_p} + \frac{w_0^2}{\sum E_i J_i}$$

$$\lambda^2 = k \cdot D_{11}$$

k – modulus of interface deformability,
E_{CE}, A_{CE}, J_{CE} – elasticity modulus, area and moment of inertia of the cross-section of expansive concrete layer,
E_p, A_p, J_p – elasticity modulus, area and moment of inertia of the cross-section of the precast element,
w_0 – distance between the centers of gravity of the layers.

Fig. 5 shows the distributions of shear stress along the interface caused by expansion in an exemplary composite element. A one-metre wide strip of a six-metre long free-ends plate was analysed. Its cross-section consists of a 20 cm high precast element (A_p = 0,2 m^2, J_p = 6,67·10^{-4} m^{-4}, E_p = 30 000 MPa) and a 10 cm layer of expansive concrete cast in-situ on it (A_{CE} = 0,1 m^2, J_{CE} = 0,833·10^{-4} m^{-4}, E_{CE} = 32 000 MPa). These distributions were obtained on the base of the expression (4) in two variants of the modulus of interface deformability. According to [9] cured concrete was attributed by modulus k= 50 000 MPa. Considering the fact that expansion occurs in young concrete, the distribution was also drawn up for a modulus five time smaller in relation to cured concrete, i.e. k=10 000 MPa. The distributions of shear stress in the interface τ are presented not in absolute values, but in relation to the values of stress of the expansion of upper layer σ_{CE}, which should be calculated according to rules [11, 18]. Shear stress equals zero almost along the whole interface, but their values are significant near the ends of the beam. Here the danger of interface cracking during expansion occurs.

Fig. 5. The distribution of shear stress τ along the interface of a strip of composite plate in relation to the self-stress of expansion of upper layer of concrete – σ_{CE}



After calculating the total shear force in the interface $T(x)$ based on the expression (6), one can the establish effective force N_{CE}' and the other forces in the cross-section:

$$N_{CE}' = N_{CE} - T(x) \tag{5}$$

$$N_p' = -N_{CE} + T(x) \tag{6}$$

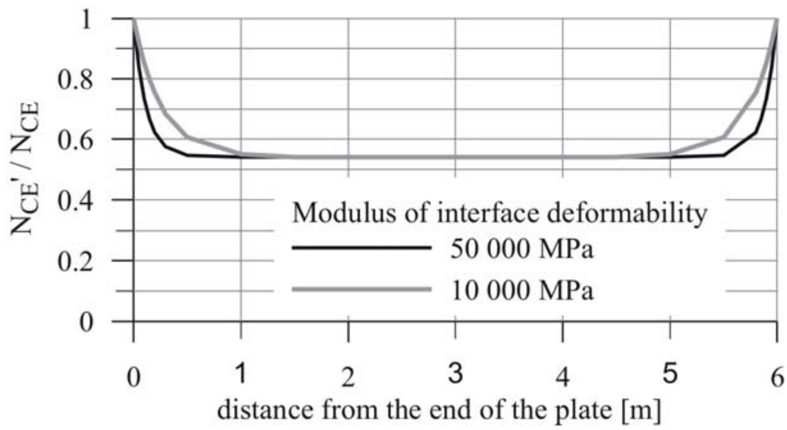
$$M_{CE}' = (-M_{CE} - T(x) \cdot w_0) \cdot \frac{E_{CE} J_{CE}}{\sum E_i J_i} \tag{7}$$

$$M_p' = -M_{CE} \cdot \frac{E_p J_p}{\sum E_i J_i} \tag{8}$$

The effective force N_{CE}' 'prestressing' the element thus depends on the total shear force in the interface $T(x)$. The bigger the shear force, the smaller the effective values of forces due to expansion. Another conclusion can also be formulated: as the force $T(x)$ changes along the interface, so the level of effective stresses also changes along the beam.

Fig. 6 shows the distributions of the effective expansion force N_{CE}' calculated while considering the deformability of the interface in relation to the initial value of the force N_{CE}. It may be noticed that the force N_{CE}' is maximal and equal to its initial value only at the end of the beam and diminishes towards the middle of the beam. The length of the section of the constant values of N_{CE}' depends of the modulus of interface deformability.

Fig. 6. The expansion force N_{CE}' in the upper expansive layer in relation to its initial value N_{CE}



CONCLUSIONS

On the basis of the tests and analyses the following conclusions can be formulated:

1. The bond strength of joint between expansive and shrinkable concrete working in different stress-strain state is greater than the bond strength of two shrinkable concretes.
2. The bond strength of a non-reinforced joint between expansive and shrinkable concrete can be cautiously calculated as the value for shrinkable concretes according to code EC2 [1] multiplied by 1,1 in the case of shrinkage-compensating concrete and by 1,5 for expansive concrete.
3. The deformability of the interface during the expansion phenomenon in the upper layer of concrete composite structures influences the values of internal forces generated due to expansion.

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Anna Halicka
Lublin University of Technology
Nadbystrzycka 40, 20-618 Lublin, Poland
Phone: 48-81-5384394
e-mail: a.halicka@pollub.pl