LABORATORY TESTS OF THIN-WALLED, TEXTILE REINFORCED CONCRETE PLATES AND RC-COLUMNS STRENGTHENED WITH TEXTILE FABRICS

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Abstract

The efficiency of the textile fabrics used as reinforcement of concrete elements was tested with relation to bending capacity of the thin concrete plates and with the reference to strengthening of concrete columns subjected to axial compression. The results of bending tests proved good effectiveness of textile reinforcement which was equivalent to conventional steel reinforced concrete elements. Values of cracking forces and deflections for textile reinforced concrete (TRC) elements were significantly higher in comparison to the plates reinforced with conventional steel reinforcement. High effectiveness of textile reinforcement was achieved due to uniform transfer of tensile forces into composite cross-section. Additional benefit of textile reinforcement in prevention of cracks represents its flexibility and very small cross section in comparison to conventional, metallic reinforcement. In consequence, smaller cracks width was observed in TRC than in traditionally reinforced concrete slabs [2]. In the second group of tests, the proposal was made for the strengthening of columns with the use of additional, thin, external layer of the orthogonal, textile fabrics and the cement mortar. Some benefits can be achieved in strengthening with textile composite in comparison to traditional methods (in particular: with the use of non-reinforced shotcrete). This solution accomplishes the methods of strengthening with the use of FRP and steel [3].

Streszczenie

Przedmiotem badań była ocena efektywności zbrojenia elementów betonowych z użyciem zbrojenia tekstylnego, w odniesieniu do nośności na zginanie cienkich płyt betonowych oraz przy wzmacnianiu słupów betonowych poddanych ściskaniu osiowemu. W badaniach na zginanie potwierdzono wysoką efektywność zbrojenia tekstylnego, odpowiadającą tradycyjnemu zbrojeniu prętami stalowymi. Dla cienkich płyt betonowych zbrojonych tekstyliami (TRC) uzyskano wartości sił rysujących i ugięć znacząco wyższe w porównaniu do płyt tradycyjnie zbrojonych prętami stalowymi. Wysoką efektywność zbrojenia tekstylnego osiągnięto dzięki równomiernemu przekazaniu sił rozciągających w przekroju kompozytu. Łatwość dopasowania układu zbrojenia do kierunków naprężeń rozciągających oraz bardzo małe przekroje przędzy wpływają korzystnie na ochronę elementów betonowych przed zarysowaniem. W rezultacie, w zginanych płytach zbrojonych tekstyliami zaobserwowano mniejszą szerokość rozwarcia rys niż w porównawczych płytach żelbetowych zbrojonych stalą [2]. W drugiej grupie badań przedstawiono propozycję wzmocnień słupów betonowych przez ułożenie dodatkowej, cienkiej warstwy zewnętrznej w formie kompozytu z zaprawy cementowej zbrojonej ortogonalną siatką tekstylną. W badaniach wykazano, że wzmocnienie słupów siatkami tekstylnymi jest, w pewnych zastosowaniach, efektywniejsze w stosunku do metod tradycyjnych (w szczególności: wzmocnień torkretem). Wzmocnienie tekstyliami stanowi uzupełnienie powszechnie znanych metod wzmacniania konstrukcji z wykorzystaniem materiałów FRP i stali [3].

Keywords: **Strengthening of RC-columns; Textile reinforcement; Thin-walled lightweight plates.**

1. INTRODUCTION

Since the diameter of the fibres in the textile reinforcement is lower than the necessary diameter of steel reinforcement and there is no minimum concrete cover requirement, the casting of very thin concrete members is possible. In such a case – neglecting the fire resistance – the thickness of structural members depends only on the necessary cover to ensure a

Table 1.
Properties and geometry of the fabrics

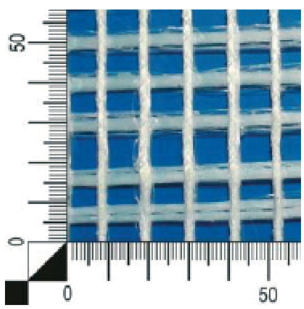
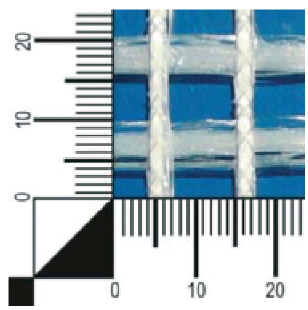
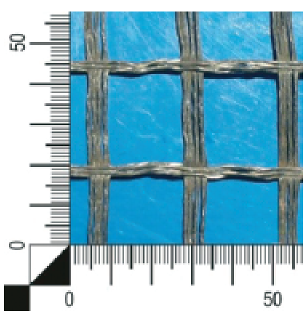
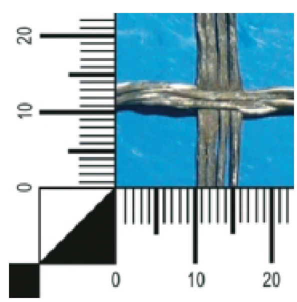
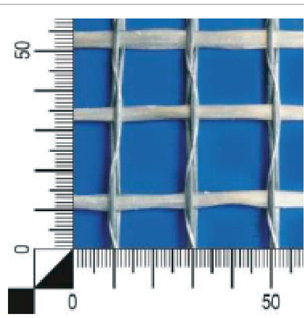
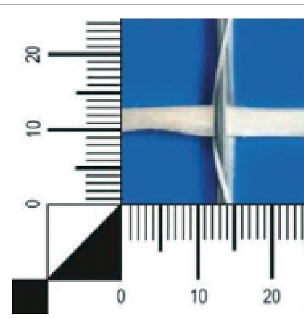
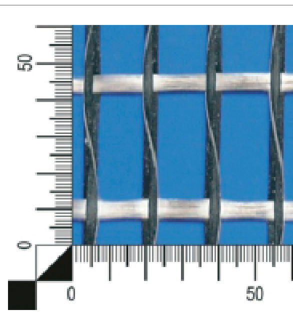
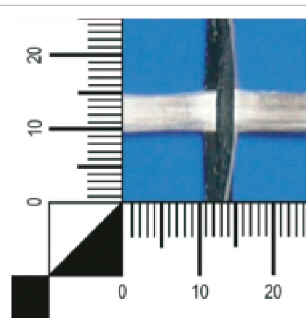
Detailed fabric view		Features
1		2
		AR-glass: – type: NWM3-002-05p, – 1600 filaments per yarn, no coating – tensile load capacity: 57 kN/m, – modulus of elasticity: 75 GPa.
		PVA with PVC coating: – ARMATEX®M geogrid PVA, with coating, – tensile load capacity: 55 kN/m, – modulus of elasticity: 58 GPa.
		S&P L200 (Low Strength): – Hybrid: carbon fibres in warp direction AR-glass yarns in weft direction, – tensile strength in warp direction: 38 kN/m, – modulus of elasticity: 240 GPa, – textile fabric additionally filled with ceramic-powder which works as an oxygen barrier at high temperature.
		S&P L500 (High Strength): – Hybrid: carbon fibres in warp direction AR-glass yarns in weft direction, – tensile strength in warp direction: 94 kN/m, – modulus of elasticity: 240 GPa, – textile fabric additionally filled with ceramic-powder (alike S&P L200)
The properties of the reference steel fabrics (plain wires Ø4.0 mm @53 mm): characteristic tensile strength: 320.0 MPa, yield strength: 240.0 MPa, tensile capacity: 57.3kN/m, modulus of elasticity: 200 GPa.		

Table 2.
Exemplary compositions and strengths of fine grained concrete

Mixture	Mean densities [kg/m^3]					w/c ratio	Mean compressive strength $f_{cm,\,cyl}$ [MPa]
	Cement	Sand 0÷1mm	Gravel 2÷4mm	Water	SP/ VS(*)		
M1	363 (a)	485.8	1334.2	196.1	-/-	0.54	36.6
M2	485 (b)	859.8	771.9	227.9	4.8/1.1	0.47	46.3

(*) SP – superplasticizer / VS – viscosity stabilizer; (a) CEM I 32.5R; (b) CEM I 42.5R

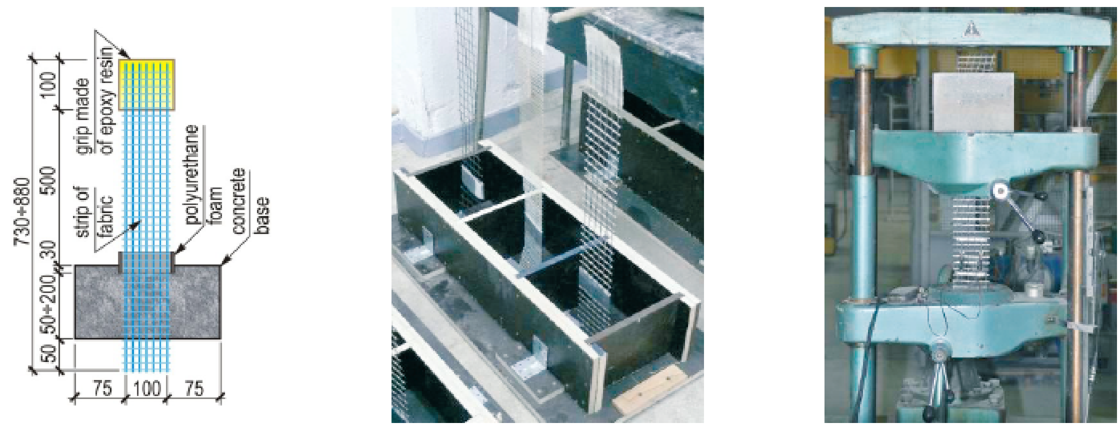


Figure 1.
Tests on anchorage length of the textiles

proper anchorage of the reinforcement and to avoid splitting failure.

Therefore, the aim of the research was to prove the efficiency of non-metallic reinforcement with the reference made to conventional, steel reinforcement.

The research programme consists of the following tests:

- the tests of bond between concrete and textile fabrics,
- the instantaneous and the long-term tests of the thin-walled plates, and
- the tests of reinforced concrete columns strengthened with the layer of textile reinforced concrete.

2. MATERIAL PROPERTIES

The main characteristics and the geometries of fabrics used in research are presented in Tab. 1.

Limitations for concrete mixtures were connected particularly with proper concrete infiltration of the fabrics with small mesh. In Authors research, after several trials of mixture components and consistency (M1), the self-compacting fine-grained concrete (M2) was selected (Tab. 2).

3. ACCOMPANYING TESTS ON ANCHORAGE LENGTH

For general information about anchorage of applied types of textile reinforcement in concrete matrix, accompanying tests on anchorage length of different textiles and the mixture M1 (Tab. 2) were performed.

The series of 3 specimens for each anchorage length from each of the textile fabrics were tested, which equals to 36 probe specimens.

For the first anchorage length tests the strips of fabric 100 mm wide and from 730 to 880 mm long were chosen and tested with an effective length of 500 mm. They were embedded in concrete base of 250×250 mm^2 in plane and with either 50, 100, 150 or 200 mm embedment length (Fig. 1). During casting of concrete in the base, the textile strip was temporarily secured at the edge by polyurethane cover as protection against accidental damage of the strip of fabric at the time of concrete vibration.

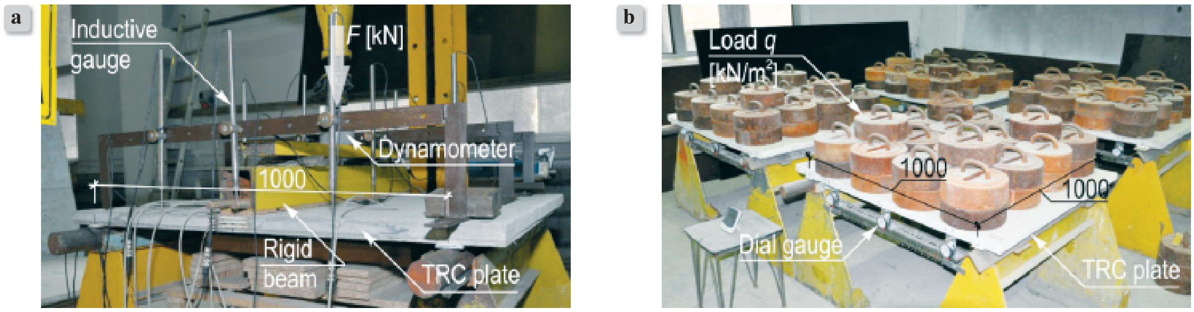


Figure 2.
Tests' set-up: a) instantaneous tests, b) long-term tests

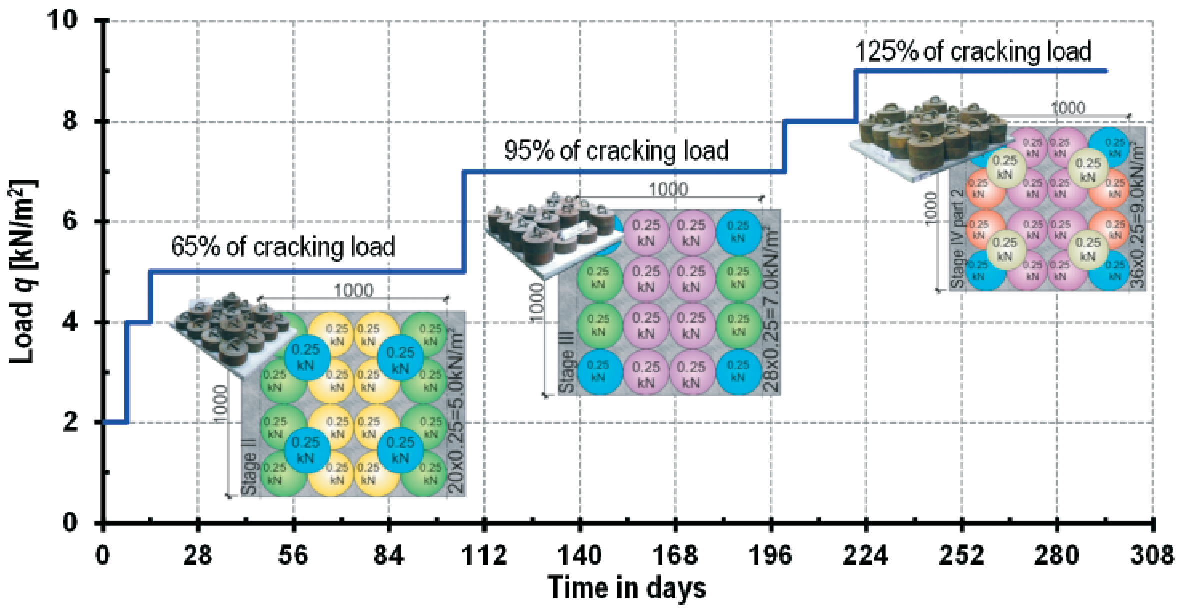


Figure 3.
Experimental programme for long-term tests

The free end of the strip of fabric was attached to the clamping jaws of the testing machine. The grip was made by the strip of epoxy resin at the end of the fabrics.

The pull-out tests of the strips of the fabrics from the concrete base were performed. The concrete base was placed at the top head of the testing machine, whereas the bottom head pulled-down the strip (Fig. 1).

In the tests the slip of the fabrics from the concrete base or its breakage was observed. Additionally, the values of the pull-out forces and displacements of the fabrics were measured.

The test results were following:

- for the smallest embedded length of 50 mm the slip of all fabrics was observed under similar average force of about 1.8 kN, so the anchorage length was insufficient in this case.
- for the embedded lengths of 100 and 150 mm, still unsatisfactory results were obtained – the slip of all fabrics was noticed.
- for the embedded length of 200 mm, all fabrics broke at the forces from 4.8 kN to 5.4 kN, and no slip was recorded.

Therefore, it seems that the minimum required anchorage length for a single layer of the fabrics taken into account must be at least 200 mm.

Nevertheless, it must be emphasized that these tests were performed only for general recognition of anchorage properties of the fabrics specified for the tests, where the one type of them originated from commercial geotextiles. It was sufficient for the simple elements in the tests, but further tests upon understanding of bond properties are planned for more complex prefabricates.

4. THE INSTANTANEOUS AND THE LONG-TERM TESTS OF THE THIN-WALLED PLATES

4.1. Tests prerequisites

The first group of test series was performed on the small plate specimens, i.e.: plates 1.20×1.00 m^2 and only 40 mm thick. The plates were prepared with the self-compacting concrete and reinforced with orthogonal textile fabrics made of alkali-resistant glass (AR-glass), poly-vinyl-alcohol (PVA) and carbon fibres (the fabrics of two types which differ 2.5 times in their strengths) – see Tab. 1. Some reference elements in tests were reinforced with steel wires. Two kinds of tests were performed. At first, all specimens were tested for bending under instantaneous static load up to failure. The elements were tested as simply supported along two edges, in three-point load scheme with concentrated force linearly distributed at mid-span. Afterwards, with reference to the values obtained in short-term bending tests, the long-term bending tests were carried on. The plot of laboratory stands is shown in Fig. 2.

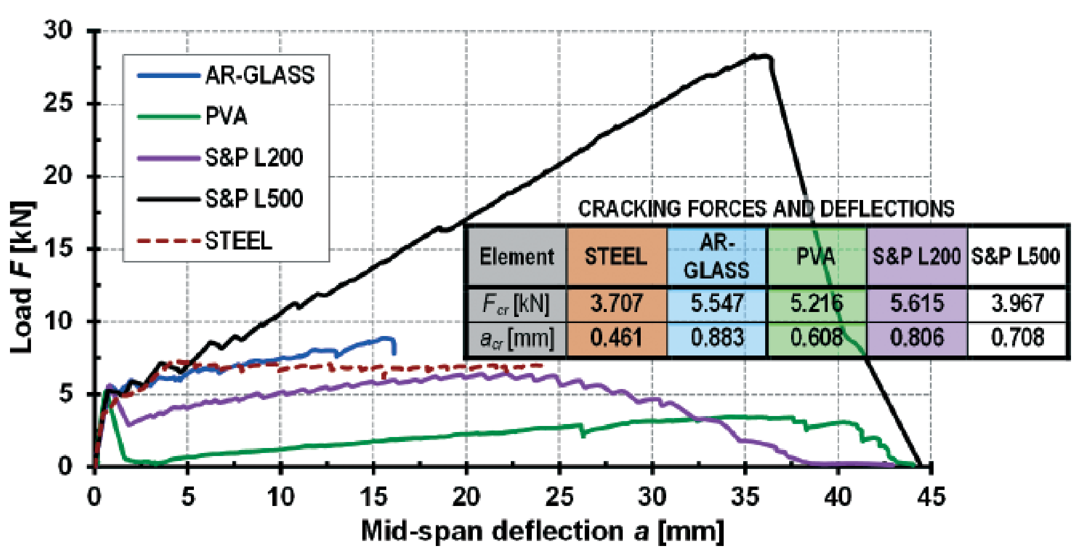
In the long-term bending tests the plates were subjected to uniformly distributed load subsequently increased up to 95% of reference cracking load, and finally above the reference cracking load (to test the post-cracking behaviour under sustained load). The period of long-term load was over six-months. In long-term tests, at first, in the pre-cracking phase, elements were subjected to the uniformly distributed load raised up to 7 kN/m^2. Load was applied in stages: at 25% and 50% of short-term cracking load during first two weeks after 28-days of hardening, and afterwards: at 65% and 95% of short-term cracking load for 3 weeks each – see Fig. 3. If cracks in slabs did not appear, further increase of load – up to 125% of short-term cracking load was applied. During the tests environmental conditions: ambient temperature and relative humidity at test stands were monitored.

During this period, textile reinforced concrete slabs performed smaller deflections in comparison to conventional, steel reinforced concrete slabs. First, small cracks (equal to 0.1 mm) were observed after final increase of load. Low crack width proved good bonding properties between concrete and textile fabrics.

4.2. Tests results

At first, all the plates performed linear behaviour before cracking. Afterwards, in post-cracking phase, the differences between elements appeared (Fig. 4).

Load-carrying capacities of the plates differed in accordance with reinforcing material, due to distinctions in fabrics' tensile strengths. The tests proved high quality of AR-glass and S&P L500 high strength carbon textile fabrics as reinforcement. For both: PVA and low strength S&P L200 carbon fibre textile fabrics, sudden drop in load-carrying capacity was observed after cracking. Afterwards, the plates performed large deflections at failure. This post-cracking behaviour of the plates is important when taking into consideration specific structural elements (e.g. road-screens), but for most practical applications the first peaks of diagrams are important, according to those presented in Fig. 4.



Element	STEEL	AR-GLASS	PVA	S&P L200	S&P L500
F_{cr} [kN]	3.707	5.547	5.216	5.615	3.967
a_{cr} [mm]	0.461	0.883	0.608	0.806	0.708

Figure 4.
The results of instantaneous tests of the plates

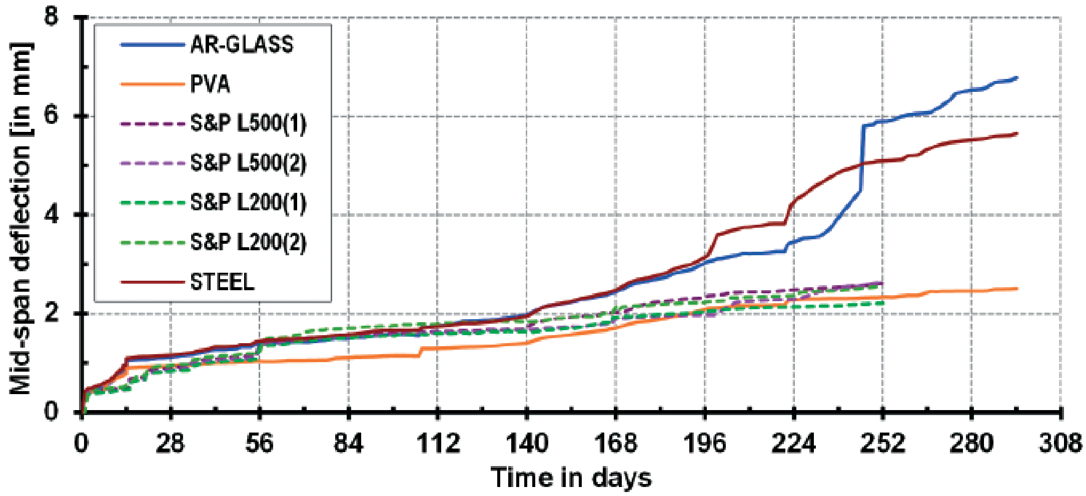


Figure 5.
The results of long-term tests of the plates

Table 3.
Properties of concretes in columns

Batch of concrete	Cylindrical specimen	F_{max} [kN]	σ_{max} [MPa]	E_{ci} [GPa]	Mean compressive strength f_{cm} [MPa]	Mean modulus of elasticity E_{cm} [GPa]
1.	2.	3.	4.	5.	6.	7.
I	W1	548.41	31.03	34.29	30.96	32.31
	W2	524.77	29.70	26.81		
	W3	568.29	32.16	35.83		
II	W1	495.67	28.05	29.80	30.40	31.08
	W2	535.11	30.28	28.87		
	W3	580.96	32.88	34.56		

Mechanic behaviour of the plates in long-term tests was examined by deflection development in time. All plates showed similar performance. At first, in the pre-cracking phase (uniformly distributed load raised up to 7 kN/m^2), textile reinforced concrete slabs performed smaller deflections in comparison to conventional, steel-reinforced concrete slabs. The highest values of deflections were measured for the plates reinforced with AR-glass fabric and the lowest: for the plates reinforced with PVA and carbon fabrics (S&P L200 and S&P L500) – see Fig. 5. First, small cracks (up to 0.1 mm) were observed after final increase of load. Low crack width proved good bonding properties between concrete and textile fabrics.

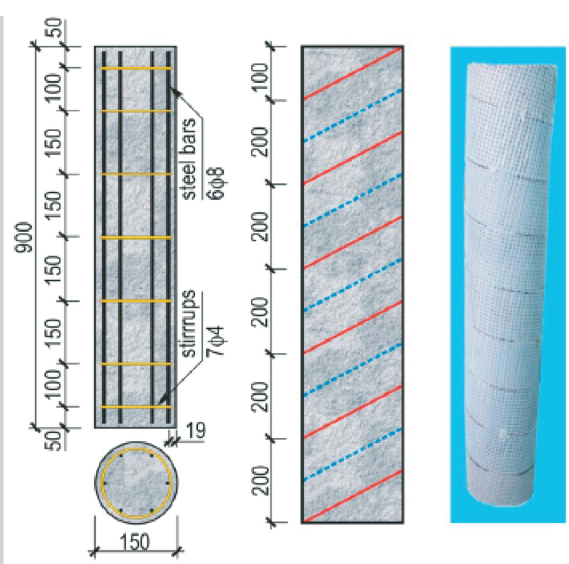


Figure 6.
Reference RC-slab and the method of strengthening of the columns

5. TESTS OF REINFORCED CONCRETE COLUMNS STRENGTHENED WITH THE LAYER OF TEXTILE REINFORCED CONCRETE

5.1. Tests materials and elements

The circular columns 150 mm in diameter and 900 mm in height were reinforced with 6Ø8 mm plain bars and Ø4 mm plain stirrups spaced at 150 mm. The properties of concretes in the columns are shown in Tab. 3.

Four different types of textile fabrics were used for strengthening: AR-Glass, two types of carbon and poly-vinyl-alcohol fibre fabrics, and "CERESIT CN83" cement mortar was used.

According to the technical data, the CN83 cement mortar has a class C35 (PN-EN 13813) and medium workability. Therefore, to increase the workability of the cement mortar with the purpose of strengthening of concrete columns, the plasticizer Sika ViscoCrete 3088 was used. As reference, two non-strengthened RC-columns, the one RC-column with CN83 cement mortar without textile reinforcement and the one concrete column were tested.

Wrapping of columns with the textile reinforcement was done at once with the use of the CN83 cement mortar. The reference RC-columns and the method of strengthening are shown in Fig. 6.

The CN83 cement mortar properties were tested on cube specimens 150×150×150 mm (Tab. 4).

5.2. Tests set-up and results

The columns were subjected to axial compression up to failure (Fig. 7).

The force increment was equal to 0.1 kN/sec. and the data were registered with 0.5 sec. intervals.

A change in the failure mode of the columns was observed with regards to the method of strengthening. Use of textile reinforcement prevented rapid failure (Fig. 7).

At pre-failure stage, the gradual development of deformations was observed in columns strengthened with textiles.

The tests results are shown in Tab. 5. The increase of compressive axial force F_{max} is connected primarily with increased cross-section of the strengthened column, not solely with the type of the fabrics. The influence of textile reinforcement on load capacity of tested elements was not observed. In this case, multi-layer, spiral textile reinforcement shall be used.

Table 4.
Properties of the CN83 cement mortar

Cube specimen	F_{max} [kN]	σ_{max} [MPa]	Mean compressive strength f_{cm} [MPa]	Mean modulus of elasticity E_{cm} [GPa]
1.	2.	3.	4.	5.
K1	776.12	34.49		
K2	708.37	31.48	35.06	31.98
K3	798.42	35.49		

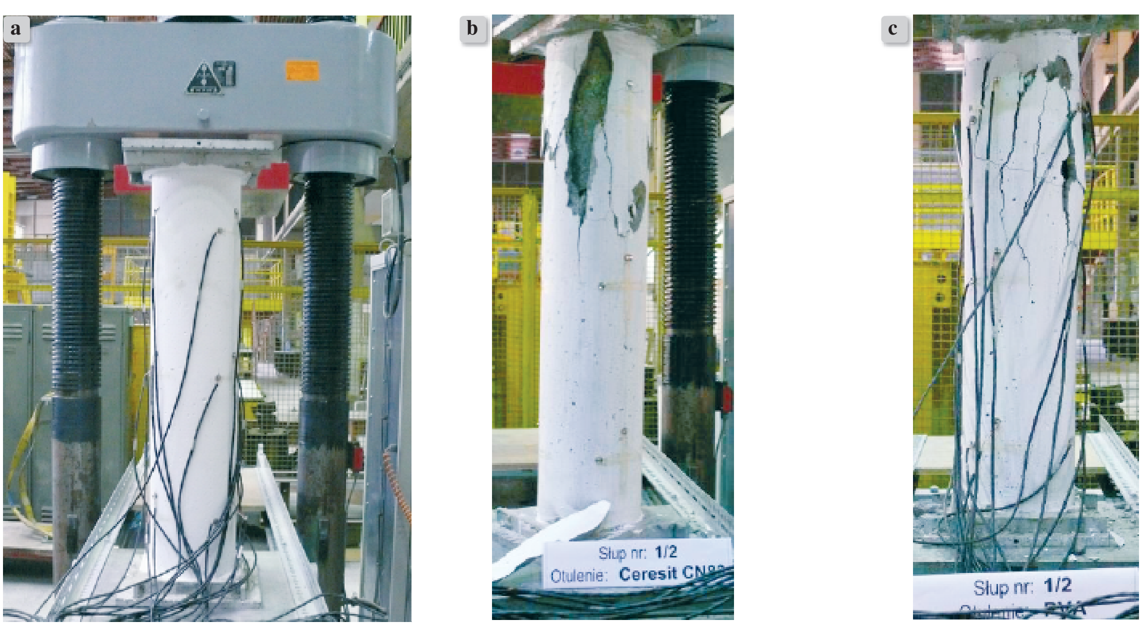


Figure 7.
Tests of columns: a) set-up, b) failure mode with cement mortar cover, c) failure mode with PVA strengthening

Table 5.
Tests results of the columns

Description of the series	Symbol	Area of cross-section A [m^2]	F_{max} [kN]	Vertical displacement u_{max} [mm]	Horizontal displacement w_{max} [mm]	σ_{max} [MPa]
1.	2.	3.	4.	5.	6.	7.
I – concrete columns	B-S1	0.0176	396.733	1.169	0.165	22.542
	B-S2		373.128	1.149	0.229	21.200
II – RC-columns	RC-S1		690.498	2.244	0.965	39.233
	RC-S2		674.012	2.246	0.894	38.296
III – columns with the cement mortar CN83 cover	CN-S1	0.0254	885.188	1.392	0.494	34.850
	CN-S2		901.252	1.227	0.444	35.482
IV – columns strengthened with AR-Glass	AR-S1		1025.140	1.899	2.774	40.360
	AR-S2		1049.813	2.002	3.486	41.331
V – columns strengthened with PVA	PVA-S1	0.0254	907.131	1.254	0.302	35.714
	PVA-S2		878.876	1.115	0.258	34.601
VI – columns strengthened with S&P L200	L2-S1	0.0201	663.818	1.204	0.454	33.032
	L2-S2		652.528	1.269	0.231	32.471
VII – columns strengthened with S&P L500	L5-S1		851.696	1.738	1.014	42.381
	L5-S2		878.884	1.816	1.139	43.734

6. CONCLUSIONS

The results of the tests of two kinds of potential utilization of textile fabrics in concrete structures: as reinforcement of thin-walled concrete plates and for the strengthening of columns have been presented shortly. As it is still new building material, at the beginning, collecting empirical data is very important [2], [3], [4].

The basic aim of the first group of the tests concerned explanation of structural behaviour of very thin concrete plates subjected to bending. The behaviour of four different textile fabrics as reinforcement has been discussed on the basis of relationship between linearly distributed, short-term static load, uniformly distributed long-term load and deflection. The test results proved good bond properties between textiles and concrete. In particular, the textile reinforcement made of carbon fibres showed high potential for structural applications.

In the second group of tests, the proposal was made for the strengthening of columns with the use of additional, thin, external layer of the orthogonal, textile fabrics and the cement mortar. Some benefits can be achieved in strengthening with textile composite in comparison to traditional methods (in particular: with the use of non-reinforced shotcrete). A change in the failure mode of the columns was observed with regards to the method of strengthening. Use of textile reinforcement prevented rapid failure.

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