BUILDING RESEARCH INSTITUTE
TESTING LABORATORIES GROUP

DEPARTMENT OF BUILDING STRUCTURES AND COMPONENTS
LABORATORY OF BUILDING STRUCTURES AND COMPONENTS LK

TEST REPORT No. LK00-01111/14/Z00NK

Customer: TRIMAL Polska Sp. z o.o.

Customer address: ul. Konduktorska 42, 40-155 Katowice

Test Object Information

Test object: Armastek composite bars for concrete reinforcement

Date of acceptance of test object: 06.10.2014

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Test object acceptance procedure: Procedures of Administration of Testing laboratories group No. 18

Testing Information

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Testing performed by:

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1. TEST METHOD / PROCEDURE:

a) Ultimate tensile strength and elasticity modulus, as described in 3.1.
b) Ultimate bending strength, as described in 3.2.
c) Ultimate shear strength, as described in 3.3.
d) Ultimate compression strength along the fibers, as described in 3.4.
e) Cross-section area and geometry of ribs, as described in 3.5.
f) Chemical resistance to alkali, as described in 3.6.
g) Creep, as described in 3.7.
h) Adhesion to concrete, as described in 3.8.

2. ELEMENTS FOR TESTING

Elements to be tested are bars for concrete reinforcement, made of composite material – glass fiber reinforced plastic (GFRP). Over the entire surface of the bars there is a braid made of fiberglass thread impregnated with epoxy resin, aimed at increasing of adhesion to concrete; thus the braid plays a role similar to that of the framework of steel reinforcing bars.

As for the samples intended for testing of tensile strength and adhesion to concrete, the manufacturer equipped them with fittings, located at the ends of the bars and made of pieces of steel pipes; the bars are set into these fittings on epoxy resin. These fittings are designed to secure the samples in the jaws of the testing machine.

As for the samples intended for creep test and test of chemical resistance to alkali, the fittings are made at Building Research Institute using S355 26.9x3.2 mm pipes, Epidian 62 epoxy resin, and curing agent Z-1.

3. DESCRIPTION OF TESTING METHOD

3.1 Ultimate tensile strength and elasticity modulus

Testing should be carried out in the same way as for metal samples according to PN-EN ISO 6892-1, using the samples of free length between the holders of at least 25 sample diameters. The sample should be secured in the testing machine in such a way as to prevent its crushing or falling down from the holder. Secant modulus $E_{T,i}$ for deformations caused by 0.2 and 0.5 destructive force should be taken as modulus of elongation. Ultimate tensile strength $R_{T,i}$ is the greatest force $F_{T,i}$ registered during the tests taken relative to nominal cross-sectional area of the sample.

3.2 Ultimate bending strength

Testing should be carried out in a Class 1 testing machine, on a freely supported sample loaded by a unit force in the center of the span. The distance between supports during testing should be equal to 10 nominal radiuses of the sample. The diameter of rod should be equal to nominal diameter of the sample to be tested. As the result of testing the maximum value of normal stresses in the sample should be indicated, which is determined from the formula as follows:

$$R_{B,i} = 8 \cdot F_m \cdot L / (\pi \cdot d_S{}^3) \qquad (1)$$

where

F_m is the maximum force obtained during testing
L is the distance between supports
d_s is the nominal diameter of the tested bar.

3.3 Ultimate shear strength

Testing should be carried out according to the diagram shown on Figure 1.

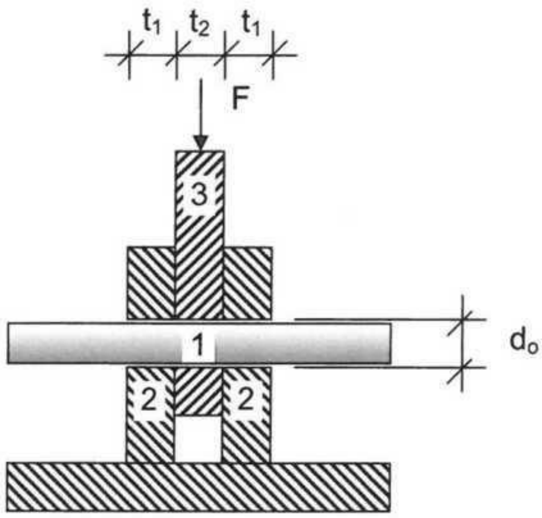

Fig. 1 - Diagram of shear strength testing

Sample "1" passes through the holes formed in sheets "2" of the base and movable blade "3". Thickness values t_1 and t_2 should be no less than diameter of hole in the sheet d_0. Diameter of hole d_0 should provide as tight fitting of the sample as possible.
Testing should be carried out in a Class 1 testing machine. Load should be applied at a rate of 5 ± 15 mm/min until the failure of the sample.
Ultimate shear strength $R_{S,i}$ is half the maximum force obtained during testing taken relative to nominal area of the sample.

3.4 Ultimate compression strength along the fibers

Testing of compression strength should be carried out in a Class l testing machine, using samples of free length equal to 3 nominal radiuses of the bar to be tested. During testing the sample should be secured in the machine, so that its ends are protected from cleavage. Ultimate compression strength $R_{C,i}$ is the greatest force registered during the tests taken relative to nominal cross-sectional area of the sample.

3.5 Cross-section area and geometry of ribs

Cross-section area should be determined using the method stated for ribbed bars in PN-EN ISO 15630-1. For calculation purposes material density should be taken equal to 2150 kg/m^3. Determination of ribs geometry involves measurement of inner diameter of the bar, outer diameter of the bar with a braid, and braiding pitch. Measurement of outer and inner diameters should be performed in two directions perpendicular to each other in at least 3 measuring points for each sample. Measurement of braiding pitch should be performed at a portion of at least ten times of its size. Instruments that provide measurement resolution of at least 0.01 mm and standard single measurement inaccuracy of no more than 0.07 mm should be used to conduct measurements.

3.6 Chemical resistance to alkali

Testing of chemical resistance to alkali comprises exposing of samples in a solution of 8 g of NaOH + 22.4 g KOH per 1000 ml of water at the temperature of 60 °C for 1,000 hours. After conditioning tensile strength of samples $R_{T,a,1000}$ is determined in accordance with paragraph 3.1, and then, based on the average tensile strength of samples before conditioning $R_{T,i,av}$, coefficient $C_{a,1000}$ is determined from the formula as follows:

$$C_{a,1000} = (1 - R_{T,a,1000} / R_{T,i,av}) \cdot 100\% \qquad (2)$$

A shorter term of conditioning is allowed, but it should not be shorter than 336 hours (14 days). In this case an extrapolation of results obtained should be made using the relationship as follows:

$$C_{a,1000} = (1 - 10^{3 \cdot \log(R_{T,a,t} / R_{T,i,av}) / \log(t)}) \cdot 100\% \qquad (3)$$

where:
t - time of sample conditioning in hours
$R_{T,t,a}$ - tensile strength of sample after t hours

3.7 Creep

Testing should be carried out using equipment and conditions that meet the requirements for isothermal relaxation testing according to PN-EN-ISO 15630-3. Testing should be carried out for at least 5 samples at initial load F_i, equal to $C_c + 2\%$, $C_c + 1\%$, C_c, $C_c - 1\%$, $C_c - 2\%$ of the average tensile strength $F_{T,i,av}$ determined in accordance with paragraph 3.1. C_c is the value of reduction of maximum load caused by creep after 1000 hours, specified by manufacturer. The load should be applied in the same way as to isothermal relaxation testing according to PN-EN-ISO 15630-3. During the testing the force should be kept constant with an accuracy of at least ± 0.5%, and registration of deformations should be performed after at least the following intervals from the end of the load application: 5 min; 30 min; 1 hour; 2 hours; 4 hours; 24 hours; 48 hours; 120 hours; 240 hours; and after 240 hours - at least once a week.
The measuring bench should be equipped in such a way as to allow to determine the time of the sample failure with an accuracy of at least 1 minute.

Recalculation of failure time t of the sample loaded with initial force F_i to reduce the load limit after 1000 hours should be performed using the relationship as follows:

$$C_{c,1000} = (1 - 10^{3 \cdot \log(F_i / F_{T,i,av}) / \log(t)}) \cdot 100\% \qquad (4)$$

3.8 Adhesion to concrete

Testing of adhesion to concrete should be carried out using the method given in Annex D to PN-EN 10080. During the testing it is required to determine force values for at least three values of sliding equal to 0.01 mm; 0.1 mm and 1.0 mm, and the maximum force that accompanies the loss of adhesion. The test result is the average stress value T_m for values of sliding of 0.01 mm; 0.1 mm and 1.0 mm, as well as loss of adhesion stress value T_r. The free end of the bar should be secured in the testing machine in such a way as to prevent its crushing or falling down from the holder.

4. TESTS RESULTS

4.1 Ultimate tensile strength and elasticity modulus

Table 1

No.	Sample ID	Nominal diameter	Cross-section area	Ultimate modulus of elongation	Ultimate tensile strength	Notes
			S_0	$E_{T,i}$	$R_{T,i}$	
		mm	mm^2	GPa	MPa	
1	LK1111 / 14/8/1	8.0	50.3	52.6	1454	
2	LK1111/14/8/2	8.0	50.3	51.3	1375	
3	LK1111/14/8/3	8.0	50.3	51.6	1536	
4	LK1111/14/8/4	8.0	50.3	51.9	1339	
5	LK1111/14/8/5	8.0	50.3	50.7	1512	
6	LK1111/14/8/6	8.0	50.3	51.2	1494	
7	LK1111/14/8/7	8.0	50.3	54.5	1399	
8	LK1111/14/8/8	8.0	50.3	54.8	1494	
9	LK1111/14/8/9	8.0	50.3	52.7	1538	
10	LK1111/14/8/10	8.0	50.3	52.7	1540	
Average values				52.4	1468	
Standard deviation				1.4	73	
Variation coefficient v %.				2.6	5.0	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				± 1.4	± 18	

Table 2

No.	Sample ID	Nominal diameter	Cross-section area	Ultimate modulus of elongation	Ultimate tensile strength	Notes
			S_0	$E_{T,i}$	$R_{T,i}$	
		mm	mm^2	GPa	MPa	
1	LK1111/14/12/1	12.0	113	49.9	1300	
2	LK1111/14/12/2	12.0	113	48.9	1332	
3	LK1111/14/12/3	12.0	113	50.9	1144	
4	LK1111/14/12/4	12.0	113	49.1	1167	
5	LK1111/14/12/5	12.0	113	49.7	1110	
6	LK1111/14/12/6	12.0	113	53.4	-	1)
7	LK1111/14/12/7	12.0	113	50.0	1126	
8	LK1111/14/12/8	12.0	113	49.9	1123	
Average values				50.2	1186	
Standard deviation				1.4	91	
Variation coefficient v %.				2.9	7.7	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				± 1.3	± 15	
1) extracting the sample from sleeve						

Table 3

No.	Sample ID	Nominal diameter	Cross-section area	Ultimate modulus of elongation	Ultimate tensile strength	Notes
			S_0	$E_{T,i}$	$R_{T,i}$	
		mm	mm^2	GPa	MPa	
1	LK1111/14/18/1	18.0	254	52.1	-	
2	LK1111/14/18/2	18.0	254	54.6	-	
3	LK1111/14/18/3	18.0	254	53.7	-	
4	LK1111/14/18/4	18.0	254	50.6	-	
5	LK1111/14/18/5	18.0	254	50.4	-	
6	LK1111/14/18/6	18.0	254	51.1	-	
7	LK1111/14/18/7	18.0	254	50.0	-	
8	LK1111/14/18/8	18.0	254	50.0	-	
9	LK1111/14/18/9	18.0	254	52.8	-	
10	LK1111/14/8/10	18.0	254	52.5	-	
Average values				52.4	-	
Standard deviation				1.4	-	
Variation coefficient v %.				2.6	-	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				± 1.4	-	

For bars 18 mm in diameter it was impossible to determine tensile strength due to insufficient strength of the ends of samples made by manufacturer.

4.2 Ultimate bending strength

Table 4

No.	Sample id	Nominal diameter	Cross-section area	Maximum force	Ultimate bending strength	Notes
			S_0	F_m	$R_{B,i}$	
		mm	mm^2	kN	MPa	
1	LK1111/14/8/31	8.0	50.3	2.205	877	
2	LK1111/14/8/32	8.0	50.3	2.355	937	
3	LK1111/14/8/33	8.0	50.3	2.282	908	
4	LK1111/14/8/34	8.0	50.3	2.375	945	
5	LK1111/14/8/35	8.0	50.3	2.290	911	
6	LK1111/14/8/36	8.0	50.3	2.225	885	
7	LK1111/14/8/37	8.0	50.3	2.072	824	
8	LK1111/14/8/38	8.0	50.3	2.161	860	
9	LK1111/14/8/39	8.0	50.3	1.964	781	
10	LK1111/14/8/40	8.0	50.3	2.268	902	
Average values				2.220	883	
Standard deviation				0.127	50	
Variation coefficient v %.				5.7	5.7	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				± 0.028	±11	
Distance between supports = 80 mm, bar diameter = 8 mm						

Table 5

No.	Sample id	Nominal diameter	Cross-section area	Maximum force	Ultimate bending strength	Notes
			S_0	F_m	$R_{B,i}$	
		mm	mm^2	kN	MPa	
1	LK1111/14/12/31	12.0	113	3.680	651	
2	LK1111/14/12/32	12.0	113	3.640	644	
3	LK1111/14/12/33	12.0	113	3.750	663	
4	LK1111/14/12/34	12.0	113	4.000	707	
5	LK1111/14/12/35	12.0	113	3.710	656	
6	LK1111/14/12/36	12.0	113	4.060	718	
7	LK1111/14/12/37	12.0	113	3.780	668	
8	LK1111/14/12/38	12.0	113	3.900	690	
9	LK1111/14/12/39	12.0	113	3.770	667	
10	LK1111/14/12/40	12.0	113	3.700	654	
Average values				3.799	672	
Standard deviation				0.141	25	
Variation coefficient v %.				3.7	3.7	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				± 0.047	±8	
Distance between supports = 120 mm, bar diameter = 12 mm						

Table 6

No.	Sample id	Nominal diameter	Cross-section area	Maximum force	Ultimate bending strength	Notes
			S_0	F_m	$R_{B,i}$	
		mm	mm^2	kN	MPa	
1	LK1111/14/18/31	18.0	254	8.050	738	
2	LK1111/14/18/32	18.0	254	9.000	825	
3	LK1111/14/18/33	18.0	254	9.140	838	
4	LK1111/14/18/34	18.0	254	9.110	835	
5	LK1111/14/18/35	18.0	254	8.230	755	
6	LK1111/14/18/36	18.0	254	8.610	789	
7	LK1111/14/18/37	18.0	254	8.260	757	
8	LK1111/14/18/38	18.0	254	8.930	819	
9	LK1111/14/18/39	18.0	254	8.420	772	
10	LK1111/14/18/40	18.0	254	9.430	865	
Average values				8.718	799	
Standard deviation				0.466	43	
Variation coefficient v %.				5.3	5.3	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				±0.109	± 10	
Distance between supports = 210 mm, bar diameter = 18 mm						

4.3 Ultimate shear strength

Table 7

No.	Sample id	Nominal diameter	Cross-section area	Ultimate shear strength	Notes
			S_0	$R_{s,i}$	
		mm	mm^2	MPa	
1	LK1111/14/8/21	8.0	50.3	185.5	
2	LK1111/14/8/22	8.0	50.3	223.8	
3	LK1111/14/8/23	8.0	50.3	185.5	
4	LK1111/14/8/24	8.0	50.3	203.9	
5	LK1111/14/8/25	8.0	50.3	184.0	
6	LK1111/14/8/26	8.0	50.3	191.5	
7	LK1111/14/8/27	8.0	50.3	213.4	
8	LK1111/14/8/28	8.0	50.3	198.9	
9	LK1111/14/8/29	8.0	50.3	228.3	
10	LK1111/14/8/30	8.0	50.3	196.5	
Average values				201.1	
Standard deviation				16.0	
Variation coefficient v %.				8.0	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				±2.6	

Table 8

No.	Sample id	Nominal diameter	Cross-section area	Ultimate shear strength	Notes
			S_0	$R_{s,i}$	
		mm	mm^2	MPa	
1	LK1111/14/12/21	12.0	113	155.8	
2	LK1111/14/12/22	12.0	113	159.2	
3	LK1111/14/12/23	12.0	113	153.0	
4	LK1111/14/12/24	12.0	113	158.0	
5	LK1111/14/12/25	12.0	113	170.0	
6	LK1111/14/12/26	12.0	113	179.0	
7	LK1111/14/12/27	12.0	113	168.0	
8	LK1111/14/12/28	12.0	113	170.4	
9	LK1111/14/12/29	12.0	113	165.1	
10	LK1111/14/12/30	12.0	113	149.9	
Average values				162.8	
Standard deviation				9.2	
Variation coefficient v %.				5.6	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				±2.1	

Table 9

No.	Sample id	Nominal diameter	Cross-section area	Ultimate shear strength	Notes
			S_0	$R_{s,i}$	
		mm	mm^2	MPa	
1	LK1111/14/18/21	18.0	254	161.1	
2	LK1111/14/18/22	18.0	254	163.1	
3	LK1111/14/18/23	18.0	254	159.2	
4	LK1111/14/18/24	18.0	254	166.2	
5	LK1111/14/18/25	18.0	254	170.3	
6	LK1111/14/18/26	18.0	254	176.2	
7	LK1111/14/18/27	18.0	254	180.6	
8	LK1111/14/18/28	18.0	254	174.7	
9	LK1111/14/18/29	18.0	254	170.9	
10	LK1111/14/18/30	18.0	254	164.7	
Average values				168.7	
Standard deviation				7.0	
Variation coefficient v %.				4.2	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				±2.1	

4.4 Ultimate compression strength along the fibers

Table 10

No.	Sample id	Nominal diameter	Cross-section area	Ultimate compression strength	Notes
			S_0	$R_{C,i}$	
		mm	mm^2	MPa	
1	LK1111/14/8/11	8.0	50.3	469.5	
2	LK1111/14/8/12	8.0	50.3	569.0	
3	LK1111/14/8/13	8.0	50.3	650.5	
4	LK1111/14/8/14	8.0	50.3	451.6	
5	LK1111/14/8/15	8.0	50.3	495.4	
6	LK1111/14/8/16	8.0	50.3	457.6	
7	LK1111/14/8/17	8.0	50.3	531.2	
8	LK1111/14/8/18	8.0	50.3	517.3	
9	LK1111/14/8/19	8.0	50.3	582.9	
10	LK1111/14/8/20	8.0	50.3	769.9	
Average values				549.5	
Standard deviation				99.5	
Variation coefficient v %.				18.1	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				±8.9	

Table 11

No.	Sample id	Nominal diameter	Cross-section area	Ultimate compression strength	Notes
			S_0	$R_{C,i}$	
		mm	mm^2	MPa	
1	LK1111/14/12/11	12.0	113	415.6	
2	LK1111/14/12/12	12.0	113	523.4	
3	LK1111/14/12/13	12.0	113	527.9	
4	LK1111/14/12/14	12.0	113	534.1	
5	LK1111/14/12/15	12.0	113	604.8	
6	LK1111/14/12/16	12.0	113	588.0	
7	LK1111/14/12/17	12.0	113	513.7	
8	LK1111/14/12/18	12.0	113	591.5	
9	LK1111/14/12/19	12.0	113	539.4	
10	LK1111/14/12/20	12.0	113	609.2	
Average values				544.8	
Standard deviation				58.1	
Variation coefficient v %.				10.7	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				± 7.1	

Table 12

No.	Sample id	Nominal diameter	Cross-section area	Ultimate compression strength	Notes
			S_0	$R_{C,i}$	
		mm	mm^2	MPa	
1	LK1111/14/18/11	18.0	254	558.4	
2	LK1111/14/18/12	18.0	254	609.1	
3	LK1111/14/18/13	18.0	254	483.4	
4	LK1111/14/18/14	18.0	254	578.5	
5	LK1111/14/18/15	18.0	254	719.9	
6	LK1111/14/18/16	18.0	254	672.0	
7	LK1111/14/18/17	18.0	254	672.0	
8	LK1111/14/18/18	18.0	254	672.8	
9	LK1111/14/18/19	18.0	254	620.9	
10	LK1111/14/18/20	18.0	254	604.0	
Average values				619.1	
Standard deviation				68.9	
Variation coefficient v %.				11.1	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K = 2)				±8.4	

4.5 Cross-section area and geometry of ribs

Table 13

Nom. diam.	Sample No.	Section area defined by mass	Ribs dimensions				Average relative area of rib
			Diameter		Braid pitch	Braid height	
			inner	outer			
d_s		**A**	d_i	d_e	C_s	h_s	f_p
mm		mm^2	mm	mm	mm	mm	_
8.0	LK1111/14/8/41	51.816	7.84	9.70	6.686	0.825	**0.123**
			8.08	9.72			
			7.97	9.66			
			7.94	9.12			
			7.90	9.38			
			7.89	9.92			
Average values			**7.94**	**9.59**	**6.686**	**0.82**	
s			**0.08**	**0.29**	-	-	
Extended inaccuracy at a confidence level of approx. 95% (K = 2)		**± 0.060**	**±0.13**	**±0.26**	**±0.012**	**±0.15**	**± 0.022**
8.0	LK1111/14/8/42	52.149	7.84	9.32	6.686	0.797	**0.119**
			8.08	9.48			
			7.97	9.54			
			7.94	9.62			
			7.90	9.48			
			7.89	9.72			
Average values			**7.94**	**9.53**	**6.686**	**0.80**	
s			**0.08**	**0.14**	-	-	
Extended inaccuracy at a confidence level of approx.		**± 0.061**	**±0.13**	**±0.16**	**±0.012**	**±0.10**	**±0.016**
8.0	LK1111/14/8/43	52.046	7.84	9.36	6.686	0.783	**0.117**
			8.08	9.50			
			7.97	9.48			
			7.94	9.68			
			7.90	9.44			
			7.89	9.54			
Average values			**7.94**	**9.50**	**6.686**	**0.78**	
s			**0.08**	**0.11**	-	-	
Extended inaccuracy at a confidence level of approx.		**± 0.077**	**±0.13**	**±0.15**	**±0.012**	**±0.10**	**±0.015**

Table 14

Nom. diam.	Sample No.	Section area defined by mass	Ribs dimensions				Average relative area of rib
			Diameter		Braid pitch	Braid height	
			inner	outer			
d_s		**A**	**d_i**	**d_e**	**C_s**	**h_s**	**f_p**
mm		mm^2	mm	mm	mm	mm	_
12.0	LK1111/14/12/41	106.23	11.81	13.48	8.453	0.867	**0.103**
			11.86	13.54			
			11.63	13.64			
			11.94	13.44			
			11.44	13.22			
			11.63	13.38			
Average values			**11.72**	**13.45**	**8.453**	**0.87**	
s			**0.18**	**0.14**	-	-	
Extended inaccuracy at a confidence level of approx. 95% (K = 2)		**±0.12**	**±0.19**	**±0.16**	**±0.012**	**±0.13**	**±0.015**
12.0	LK1111/14/12/42	106.41	11.95	13.15	8.502	0.755	**0.089**
			11.65	13.55			
			11.76	13.25			
			11.99	13.33			
			11.90	13.13			
			11.74	13.65			
Average values			**11.83**	**13.34**	**8.502**	**0.76**	
s			**0.13**	**0.21**	-	-	
Extended inaccuracy at a confidence level of approx.		**±0.12**	**±0.16**	**±0.21**	**±0.012**	**±0.13**	**±0.015**
12.0	LK1111/14/12/43	104.39	11.82	13.73	8.507	0.765	**0.090**
			11.62	13.21			
			11.70	13.13			
			11.91	13.43			
			11.70	13.61			
			11.66	12.51			
Average values			**11.74**	**13.27**	**8.507**	**0.77**	
s			**0.11**	**0.44**	-	-	
Extended inaccuracy at a confidence level of approx.		**±0.12**	**±0.15**	**±0.37**	**±0.012**	**±0.20**	**± 0.024**

Table 15

Nom. diam.	Sample No.	Section area defined by mass	Ribs dimensions				Average relative area of rib
			Diameter		Braid pitch	Braid height	
			inner	outer			
d_s		**A**	**d_i**	**d_e**	**C_s**	**h_s**	**f_p**
mm		mm^2	mm	mm	mm	mm	_
18.0	LK1111/14/18/41	242.12	17.48	20.27	10.490	1.083	**0.103**
			17.60	19.75			
			17.66	19.63			
			17.80	19.45			
			17.81	19.13			
			17.34	20.49			
Average values			**17.62**	**19.78**	**10.490**	**1.08**	
s			**0.18**	**0.51**	-	-	
Extended inaccuracy at a confidence level of approx. 95% (K = 2)		**±0.37**	**±0.19**	**±0.43**	**±0.012**	**±0.24**	**± 0.022**
18.0	LK1111/14/18/42	241.61	17.14	20.03	10.288	1.070	**0.104**
			17.89	20.07			
			17.35	19.51			
			17.91	19.93			
			17.47	19.73			
			17.64	18.95			
Average values			**17.57**	**19.71**	**10.288**	**1.07**	
s			**0.31**	**0.42**	-	-	
Extended inaccuracy at a confidence level of approx.		**±0.37**	**±0.27**	**±0.36**	**±0.012**	**±0.23**	**± 0.022**
18.0	LK1111/14/18/43	241.14	17.15	18.67	10.798	0.955	**0.088**
			17.86	20.39			
			17.15	18.75			
			17.94	19.99			
			17.37	19.39			
			17.86	19.63			
Average values			**17.56**	**19.47**	**10.798**	**0.96**	
s			**0.37**	**0.68**	-	-	
Extended inaccuracy at a confidence level of approx.		**±0.37**	**±0.33**	**±0.57**	**±0.012**	**±0.33**	**± 0.030**

4.6 Chemical resistance to alkali

Table 16

No.	Sample id	Nominal diameter	Cross-section area	Loss of initial stability after 336 hours	Extrapolated loss of initial stability after 1000 hours	Notes
			S_0	$C_{a,336}$	$C_{a,1000}$	
		mm	mm^2	%	%	
1	LK1111/14/8/11	8.0	50	18.8%	21.9%	
2	LK1111/14/8/12	8.0	50	15.4%	18.1%	
3	LK1111/14/8/13	8.0	50	17.9%	20.9%	
4	LK1111/14/8/14	8.0	50	30.5%	-	1)
5	LK1111/14/8/15	8.0	50	16.9%	19.8%	
6	LK1111/14/8/16	8.0	50	40.8%	-	1)
Average values				17.3%	21.0%	
Extended inaccuracy of a single measurement at a confidence level of approx. 95% (K=2)				± 1.3%	±2.1%	
1) extracting the sample from sleeve - the result is rejected						

4.7 Creep

Table 17

Sample name							
LK1111/14/12/51		LK1111/14/12/52		LK1111/14/12/54		LK1111/14/12/55	
Load							
80% $F_{T,i,av}$		76% $F_{T,i,av}$		68% $F_{T,i,av}$		64% $F_{T,i,av}$	
Testing time	Deformations increase	Testing time	Deformations increase	Testing time	Deformations increase	Testing time	Deformations increase
[h]	[%]	[h]	[%]	[h]	[%]	[h]	[%]
0.083	0.000	0.083	0.000	0.083	0.000	0.83	0.000
0.5	0.137	0.5	0.071	0.5	0.035	0.5	0.046
1	0.172	1.0	0.087	1.0	0.054	1.0	0.058
Sample failure occured after 2.5 [h]		4.0	0.119	5.0	0.086	5.0	0.084
		24.0	0.206	24.5	0.130	24.5	0.137
		49.5	0.283	49.0	0.172	49.0	0.161
		120	0.323	120	0.203	120	0.197
		192	0.399	192	0.215	192	0.207
		288	0.626	288	0.239	288	0.226
		360	0.882	432	0.244	432	0.234
		Sample failure occured after 428 [h]		696	0.269	696	0.254

Table 18

Sample name					
LK1111/14/12/57		LK1111/14/12/58		LK1111/14/12/59	
Load					
56% $F_{T,i,av}$		52% $F_{T,i,av}$		48% $F_{T,i,av}$	
Testing time	Deformations increase	Testing time	Deformations increase	Testing time	Deformations increase
[h]	[%]	[h]	[%]	[h]	[%]
0.83	0.000	0.83	0.000	0.83	0.000
0.5	0.008	0.5	0.021	0.5	0.019
1.0	0.018	1.0	0.026	1.0	0.028
4.0	0.036	4.0	0.049	4.0	0.044
24.0	0.065	24.0	0.082	24.0	0.061
50.	0.080	50.	0.099	50.	0.089
120	0.099	120	0.122	120	0.090
192	0.110	192	0.135	192	0.109
288	0.126	288	0.152	288	0.140
432	0.126	432	0.154	432	0.145
696	0.144	696	0.176	696	0.144

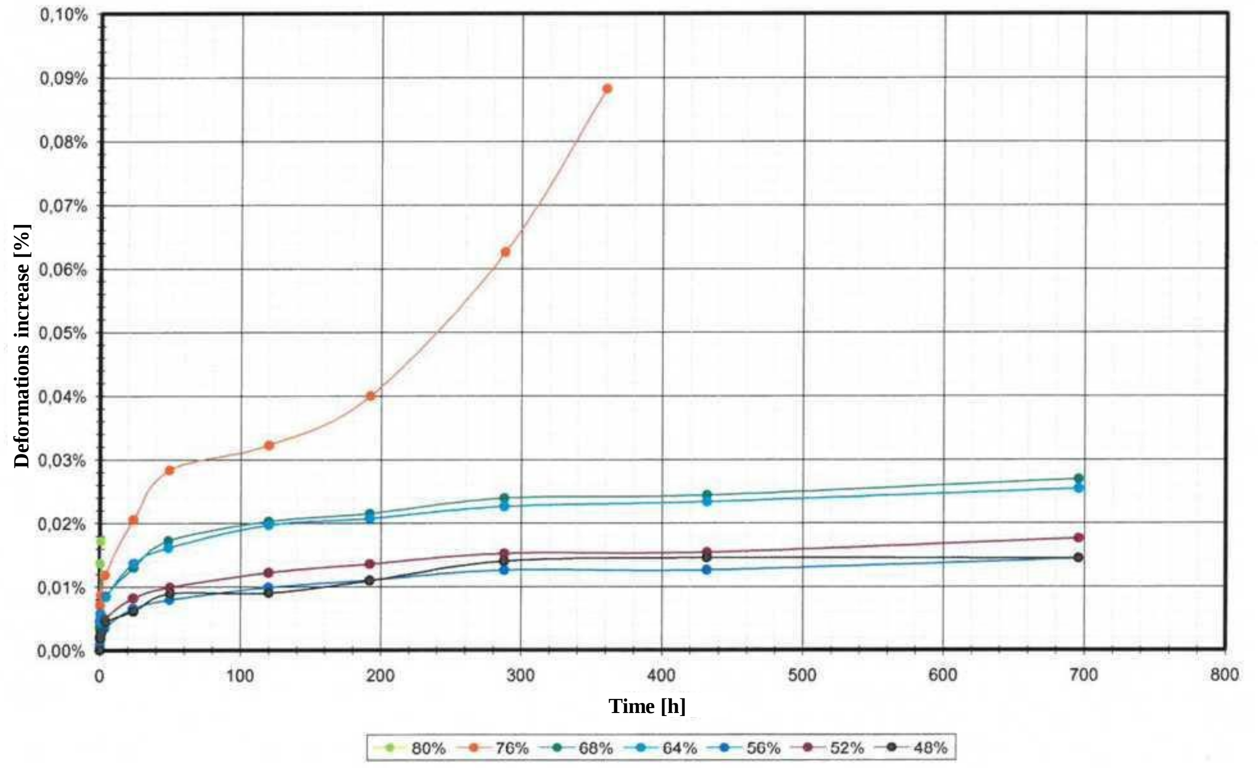

Fig. 1 – Deformations increase over time for tested samples

4.8 Adhesion to concrete

Testing was conducted for design strength of concrete equal to 25 MPa (concrete class C25/30). Ratio of actual average compressive strength of concrete to design value is 0.72.

Table 19

Nominal diameter of bar	Force at sliding 0.01 mm	Force at sliding 0.1 mm	Force at sliding 1 mm	Maximum force	Average stress during sliding	Stress of adhesion loss
mm	kN	kN	kN	kN	MPa	MPa
8	1.19	6.45	10.10	11.20	8.19	15.5
8	0.96	6.21	8.36	9.82	7.17	13.6
8	0.86	4.51	10.34	11.41	7.25	15.8
8	1.21	7.15	8.49	9.78	7.78	13.5
8	1.55	5.88	9.65	11.22	7.88	15.5
8	1.70	7.31	10.24	14.00	8.89	19.4
12	2.60	11.00	19.50	25.50	6.79	15.7
12	3.38	8.90	22.05	25.00	7.04	15.4
12	4.75	9.85	23.40	25.15	7.80	15.5
12	4.50	11.25	23.00	25.30	7.95	15.6
12	3.65	14.20	22.10	24.90	8.20	15.3
12	2.85	9.45	23.05	25.10	7.25	15.4

5. EVALUATION OF TEST RESULTS

5.1 Requirements

Table 20

No	Properties	Requirements	Testing Methods
1	**2**	**3**	**4**
1.	Tolerance of area defined by weight from nominal value[1]	±8%	according to 3.5
2.	Inner diameter d_i [mm]	$d_s -1 \leq d_i \leq d_s$ (d_s - nominal diameter of bar in mm)	
3.	Outer diameter d_e [mm]	$d_s \leq d_e \leq d_s +1$ (d_s - nominal diameter of bar in mm)	
4.	Braid pitch c_s [mm]	$0.4\ d_s +3 \leq c_s \leq 0.4\ d_s +4$ (d_s - nominal diameter of bar in mm)	
5.	Minimum reinforcement ratio f_p [2] [-]	0.070	
6.	Ultimate tensile strength $R_{T,i}$ [MPa]	≥ 1100	according to 3.1
7.	Ultimate modulus of elongation $E_{T,i}$ [GPa]	50-55	
8.	Ultimate compression strength along fibers $R_{c,i}$ [MPa]	≥ 350	according to 3.4
9.	Ultimate shear strength $R_{s,i}$ [MPa]	≥ 150	according to 3.3
10.	Reduction of load limit due to exposure to alkaline medium $C_{a,1000}$ [%]	$\leq 25\%$	according to 3.6
11.	Reduction of load limit caused by creep after 1000 hours, $C_{c,1000}$ [%]	$\leq 25\%$	according to 3.7
12.	Adhesion to concrete C25/30 Average value of stress T_m, [MPa] Stress of adhesion loss T_r [MPa]	$0.098(80-1.2\ d_s)$ $0.098\ (130-1.9\ d_s)$ (d_s - nominal diameter of bar in mm)	according to 3.8
Bar area is determined on the basis of accepted material density, which is 2150 kg/m^3 Ratio determined from relationship $(d_e - d_i) / (2 - c_s)$			

Properties listed in paragraphs 1-5-9 of Table 20 should be included in the scope of current testing of products, and properties listed in paragraphs 10 and 11 - in the scope of periodic testing.

As an evaluation criterion to ensure long-term quality level 5% quantile for ultimate tensile strength $R_{T,i}$ and 10% for other properties that are within the scope of the current testing should be taken.

5.2 Evaluation of results

The method of evaluation of testing results given in Annex C to PN-EN 1992-1-1 is applied. 0.97 and 1.03 of the normative value of considered property are taken as absolute minimum and maximum respectively. The required value for average tensile strength is set to 1,120 MPa, i.e. standard value is increased by 20 MPa.

5.2.1 Tensile strength and elasticity modulus

Table 21 summarizes test results and required values.

Table 21

Nominal diameter	Modulus of elongation			Tensile strength	
	minimum	average	maximum	minimum	average
d_s	$E_{T,i,min}$	$E_{T,i,av}$	$E_{T,i,max}$	$R_{T,i,min}$	$R_{T,i,av}$
mm	GPa	GPa	GPa	MPa	MPa
8	50.7	52.4	54.8	1339	1468
12	48.9	50.2	53.4	1110	1186
18	50.0	51.8	54.6	-	-
Required values					
-	≥ 48.5	50-55	≤ 56.7	≥ 1067	≥ 1120

The obtained test results satisfy the requirements listed in Table 20.

5.2.2 Shear strength

Table 22 summarizes test results and required values.

Table 22

Nominal diameter	Shear strength	
	minimum	average
d_s	$R_{s,i,min}$	$R_{s,i,av}$
mm	MPa	MPa
8	184	201
12	150	163
18	159	169
Required values		
-	≥ 145	≥ 150

Tested samples satisfy requirements listed in table 20.

5.2.3 Compression strength along the fibers

Table 23 summarizes test results and required values.

Table 23

Nominal diameter	Compression strength	
	minimum	average
d_s	$R_{C,i,min}$	$R_{C,i,av}$
mm	MPa	MPa
8	184	201
12	150	163
18	159	169
Required values		
-	≥ 145	≥ 150

Tested samples satisfy requirements listed in table 20.

5.2.4 Cross-section area and geometry of ribs

Table 24 summarizes values obtained during testing, together with requirements.

Table 24

Nominal diameter	Cross-section area			Coefficients of reinforcement	
	minimum	average	maximum	minimum	average
d_s	A_{min}	A_{av}	A_{max}	$f_{p,min}$	$f_{p,av}$
mm	mm^2	mm^2	mm^2	-	-
8	Test resuts				
	51.8	52.0	52.1	0.117	0.120
	Required values				
	≥ 44.9	46.2-54.3	≤ 55.9	≥ 0.068	≥ 0.070
12	Test resuts				
	104.4	105.7	106.4	0.089	0.094
	Required values				
	≥ 100.9	104.0-122.1	≤ 125.8	≥ 0.068	≥ 0.070
18	Test resuts				
	241.1	241.6	242.1	0.088	0.099
	Required values				
	≥ 227.1	234.1-274.8	≤ 283.1	≥ 0.068	≥ 0.070

The obtained test results satisfy the requirements listed in table 20.

5.2.5 Chemical resistance to alkali

Table 25 summarizes test results and required values.

Table 25

Nominal diameter	Extrapolated loss of stability after 1000 hours	
	minimum	average
d_s	$C_{a,1000,min}$	$C_{a,1000,max}$
mm	%	%
8	19.7%	21.0%
	Required values	
-	≤ 25.8%	≤ 25.0%

Tested samples satisfy requirements listed in table 20.

5.2.6 Creep

Among 7 samples tested, the one loaded with an initial force equal to 80% of ultimate tensile strength was destroyed in the initial testing phase. Among the remaining 6 samples, the one loaded with an initial force equal to 76% of ultimate tensile strength was destroyed after

428 hours from the start of the testing. This corresponds to the value of parameter $C_{c,1000}$, which amounts to 26.9%. As a result of applying too low load levels for further 5 samples, they were not destroyed after 696 hours. However the character of "deformation-time" curves obtained up to this point allows to conclude, that they can reach the average value of parameter $C_{c,1000}$ under 25%. For this reason, it can be concluded that the tested bars have the required properties listed in 5.1.

5.2.7 Adhesion to concrete

For bars with a diameter of 8 mm the required average stress during sliding 0.01 mm; 0.1 mm and 1 mm is 6.90 MPa according to 5.1, and the stress of adhesion loss is 11.25 MPa. All tested bars with a diameter of 8 mm satisfy these requirements.
For bars with a diameter of 12 mm the required average stress during sliding 0.01 mm; 0.1 mm and 1 mm is 6.43 MPa according to 5.1, and the stress of adhesion loss is 10.51 MPa. All tested bars with a diameter of 12 mm satisfy these requirements.

6. SCOPE AND CONDITIONS OF APPLICATION OF ARMASTEK COMPOSITE BARS

6.1 Designation and scope of application of the product

ARMASTEK composite bars with diameters of 4 ± 8 mm are designed to be used in elements of tension and compression reinforcement of structures made of reinforced concrete. These bars should not be used for reinforcement of structures that are subjected to dynamic loads and multiple changes. It is prohibited to bend ARMASTEK bars at the construction site, as well as to connect them in any way, but to overlap, according to rules contained in PN-EN 1992-1-1.

6.2 Conditions of application of the product

In calculations of reinforced concrete structures according to PN-EN 1992-1-1 the initial data for materials for reinforcement should be taken as in Clause 3.2.7 of the standard, amended taking into account the absence of A and B branches in Fig. 3.8.
Partial safety coefficient γ_s should be taken equal to 1.25.

Instead of the specified limit of plasticity f_{yk}, value of f_{tk} defined for tension reinforcement should be taken according to the following formula:

$$f_{tk} = R_{T,i}/n_{env} \qquad (5)$$

while for compression the relation is as follows:

$$f_{tk} = R_{C,i}/n_{env} \qquad (6)$$

where

$$n_{env}=1/0.75^{n+2} \qquad (7)$$

The value of parameter n in formula (7) is as follows:

$$n = n_{mo} + n_T + n_{SL} \quad (8)$$

where

n_{mo} = –1 for exposure class XC1
n_{mo} = 0 for exposure class XC3, XD1, XD3, XS1, XS3
n_{mo} = 1 for exposure class XC2, XC4, XD2, XS2, XA1, XA2, XA3

n_T = 0.5 for use at temperatures not exceeding 15 °C – average annual value – typical outdoor temperature conditions in Poland
n_T = 0 for use at temperatures not exceeding 25 °C – average annual value
n_T = 0.5 for use at temperatures not exceeding 35 °C – average annual value

n_{SL} = 1 for operation period of 1 year
n_{SL} = 2 for operation period of 10 years
n_{SL} = 2 for operation period of 50 years
n_{SL} - 3 for the operation period of 100 years

In calculations taking into account the effect of short-term loads, the value of module $E_s = E_{T,i}$ should be taken. In calculations taking into account the effect of long-term loads an additional increment of deformations (expressed in abstract values) should be considered, equal to:

$$\Delta\varepsilon = 10^{a \cdot \log(t) + b} \quad (9)$$

Values of parameters *a* and *b* in formula (9) are as follows:

$$a = -0.14 \cdot \sigma_S / R_{T,i} + 0.39 \quad (10)$$

and

$$b = 2.14 \cdot \sigma_S / R_{T,i} - 5.72 \quad (11)$$

where

t - time of prolonged exposure in hours
σ_S - tensile stresses caused by long-term part of design loads.

In case where stresses σ_S have compressing character $R_{C,i}$ should be used in formulas (10) and (11) instead of $R_{T,i}$.

7. FINAL PROVISIONS

Composite bars tested in this project satisfied the conditions listed in 5.1. Thus, it can be concluded that ARMASTEK composite bars with diameters of 4 ± 18 mm can be used for concrete reinforcement on conditions and to extent specified in paragraph 6 and its subparagraphs.
This project does not include fire safety issues.

Person responsible for testing:
dr eng. Przemysław Więch
Title, name
/Signature/
Signature

Report approved by:
dr eng. Artur Piekarczuk
Title, name
/Signature/
Signature

Warsaw, May 11, 2015

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