Pergamon

Cement and Concrete Research 31 (2001) 1459–1465

CEMENT AND CONCRETE RESEARCH

Mechanical properties of concrete cast in fabric formworks

Mahdi Al Awwadi Ghaib, Jaroslaw Górski*

Faculty of Civil Engineering, Technical University of Gdańsk, G. Narutowicza 11/12, Gdańsk 80-952, Poland

Received 29 November 2000; accepted 7 June 2001

This work was done to honor the late Professor Kazimierz Braun who supervised the study.

Abstract

Fabric formworks are permeable sheets made of synthetic textiles. The forms take the designed shapes (bags, bolsters, mattresses, or shuttering) under the pressure of pumped concrete mixes or cement mortars. The monolith of the structures built of these elements depends on the adhesion of the cement mortar or paste that drains throughout the fabric. The paper is aimed to provide civil engineers with guidelines for selecting a suitable textile and concrete mix. To achieve this, a series of tests was carried out. First, mechanical characteristics of various fabrics and their permeability were investigated. Next, concrete cubes were prepared from 12 concrete mixes molded in four types of fabrics. The cubes were subjected to destructive tests. On the basis of the laboratory results, the concrete compressive strength as a function of formwork and concrete mechanical parameters was obtained. The correctness of this relationship was estimated by use of the statistical analysis. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Mechanical properties; Permeability; Curing; Concrete

1. Introduction

The range of fabric form applications has expanded rapidly over the last decade, owing to the development in synthetic production technology and the concrete pumping technology [1–7]. Some examples of using concrete elements in fabric forms are presented in Fig. 1. In fact, the rapid growth of fabric form applications is paralleled by heavily patented circumstances (e.g., see Refs. [8,9]). Consequently, most of the available publications and technical reports are reduced to a historical outline of the fabric form applications and the economical benefits gained (cf. Ref. [10]).

Conventionally, the method of casting in situ concrete involves the use of rigid shuttering fabricated from timber or steel. These forms provide an impermeable container holding the fluid concrete throughout the first hydration period. In an alternative method, some flexible formworks, constructed from permeable woven textiles (nylon, polyesters, polypropylene, etc.), provide porous walls to the concrete pumped in. This allows an excess of water to pass freely out of the formworks. Consequently, a good quality of concrete was obtained by use of this technique. A porous wall is a fundamental feature of the method.

In this work, the chemical and the microscopic characteristics were tested for 10 various synthetic fabrics. In four of them, the mechanical properties were also examined. The phenomenon of squeezing fluid through the walls of the textiles was investigated using a specially designed apparatus. The permeability tests for 48 concrete mixes (192 specimens) allowed for selecting appropriate fabrics for the concrete form design.

To analyse the compressive strength of the concrete mixes cast in fabric forms, a destructive test was carried out. The test was intended to investigate the effect of the textile pore size on the compressive strength of the concrete mixes. Mattresses tailored from four kinds of fabric were filled with 12 concrete mixes. After 3 days, concrete cubes were cut out and subjected to destructive tests. The analysis included 232 samples. An optimum pore size for textile forms was determined. An equation estimating the concrete compressive strength was also elaborated.

The discussion is limited to the relationship between the fabrics, only as containers, and the concrete mixes, as the filling material. The role of the textile as a structural element has been neglected in the investigations.

---

* Corresponding author. Tel.: +48-58-347-21-47; fax: +48-58-347-16-70.

E-mail address: jgorski@pg.gda.pl (J. Górski).

PII: S0008-8846(01)00568-3

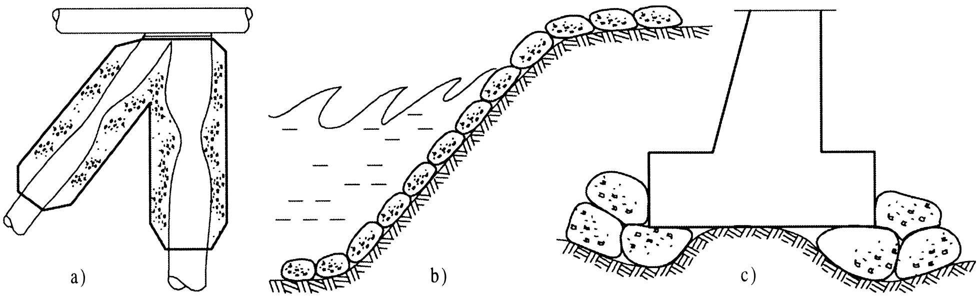

Fig. 1. Examples of fabric forms applications: (a) pile jacketing, (b) erosion control surface, and (c) bridge pier unclear pinning.

The paper is only a short presentation of the results submitted in the PhD dissertation of Al Awwadi Ghaib [11]. Some discussions of the investigations can also be found in Refs. [12–14].

2. Materials used in the laboratory tests

2.1. Mechanical characteristics of fabrics

The authors tested 10 kinds of textile produced in Pabianice (Poland) with average microscopic opening sizes (mos) ranging from 0.15×10^{-3} to 0.68×10^{-3} m. On the basis of the chemical and microscopic tests, four kinds of fabrics were chosen for further analysis. Five samples (0.50×0.30 m) of these textiles in the warp direction and five samples in weft direction were tested according to Polish Standard Code [15]. The obtained average results are presented in Table 1.

2.2. Characteristics of concrete mixes

Commercially available Portland cement with fly ash made in Poland was used throughout the investigation. The cement physical properties and the chemical composition were tested according to the Polish Standard Code [16], and the results are given in Table 2.

The aggregate used in the laboratory tests was commercially obtained from natural sources around Gdańsk. A sieve analysis of fine and course aggregate is determined in accordance with the Polish Standard Code [17]. The results are presented in Fig. 2.

Forty-eight concrete mixes used in the experimental program were prepared. In Table 3, only data for 12 exemplary mixes are presented.

3. Permeability tests of fabric forms filled with concrete

The permeability tests are aimed to calculate the quantity of fluid discharged out of the fabrics, taking into account the following effects: type of textile, initial water–cement (w/c) ratio, quantity of cement used (richness), and the external pressure applied. There appears to be a lack of technical details in the published papers that deal with the permeability of fabrics filled with concrete. The publications usually investigate the problem from the geotechnical point of view only (e.g., Ref. [18]).

The authors designed an apparatus for measuring the quantities of fluids penetrating through the fabrics, as shown in Fig. 3. Comparative tests were carried out in four different fabrics (Table 1) and filled with 48 concrete mixes.

To investigate the influence of the fabric mos, an external pressure of 200 kN/m^2 was applied for 1 min by an air pump. The amount of the discharged liquids was recorded at eight time intervals starting immediately after the completion of the concrete casting. Then the final quantity of liquids was dried in an electric oven at 110°C and a quantity

Table 1
Physical properties of fabrics used in the experiment

Fabric type	Weight, kg/m^2 × 10^{-3}	Pore size (mos), [m] × 10^{-3}	Percentage of pores	Test direction	Average Elongation [%]	Maximum load [kN]	Tensile stress [MPa]
PT/45	170	0.14 ÷ 0.16	2	warp	35	9.1	60.6
				weft	28	6.5	43.1
PT/48	236	0.35	7	warp	37	11.2	49.9
				weft	35	7.6	33.8
PT/67s	287	0.53 ÷ 0.60	12	warp	26	8.8	54.0
				weft	23	5.6	37.0
PT/67w	310	0.68	17	warp	28	10.2	52.0
				weft	34	8.2	41.0

Table 2
Portland cement properties

Physical properties		Chemical properties [%]	
Density	3100 kg/m^3	SiO_2	20.08
Fineness (Blaine)	315.8 m^2/kg	CaO	60.36
Setting time		Fe_2O_3	2.89
Initial	3:17 h:min	Al_2O_3	6.51
Final	6:17 h:min	MgO	1.86
Compressive strength		SO_3	2.40
3 days	25.22 MPa	Loss on ignition	1.97
7 days	32.17 MPa	Insoluble residue	4.65
28 days	43.60 MPa		

Table 3
Representative concrete mixes used in the experimental program

Mix number	Unit content [kg/m^3] Cement	Sand	Gravel	Water	w/c ratio	Consistency
B3	250	670	1430	160	0.64	plastic
B5	250	670	1430	185	0.75	heavy flowing
B6	250	670	1430	205	0.82	flowing
C2	300	780	1170	180	0.60	plastic
C4	300	780	1170	216	0.72	heavy flowing
C6	300	780	1170	246	0.82	flowing
D2	350	615	1350	200	0.57	plastic
D4	350	615	1350	245	0.70	heavy flowing
D6	350	615	1350	290	0.83	flowing
E3	400	570	1250	235	0.59	plastic
E5	400	570	1250	285	0.71	heavy flowing
E6	400	570	1250	325	0.81	flowing

of the lost cement and some very fine aggregate was calculated. A comparison of the final amount of the discharged liquid is shown in Table 4.

The influence of the type of fabric and elapsed time on the amount of the discharged liquids for two kinds of concrete mixes is demonstrated in Fig. 4.

The 192 tests allowed for formulating the following remarks.

(1) In all kinds of mixes, about 30% of the total discharged liquids drained out during the first 5 min of the test. The rate of the discharged liquids fell off with time and most of the discharges occurred in 15–30 min. The flowing fluid was not only a constituent of the excess of water, but also of the cement mortar and the cement paste.

(2) The quantity of the lost cement was governed by the initial w/c ratio in three types of fabrics, i.e., PT/48, PT/67s, and PT/67w. The loss of cement in PT/45 fabric was not influenced by the initial w/c ratio.

(3) There were some noticeable changes in the w/c ratio in all mixes and in all types of fabrics. Most of the final w/c ratios were smaller than the initial w/c ratios except for the mixes cast in the PT/67w type of fabric formwork. The average reductions of the w/c ratios before setting were about 15%, 20%, 10%, and -2% in fabric formworks of type PT/45, PT/48, PT/67s, and PT/67w, respectively.

(4) The concrete in the fabric formworks set rapidly, even though the initial w/c ratio was high.

4. Compressive strength of concrete cast in fabric forms

4.1. Laboratory tests

Four kinds of fabrics, presented in Table 1, had been tailored for mattresses and bags at an upholstery workshop, and then filled with 12 concrete mixes (Table 2) under a pressure of 200 kN/m^2 using a concrete pump (Fig. 5). The concrete mattresses were kept wet for 3 days. Next, cubes of dimension $10 \times 10 \times 10$ cm were cut out by use of an electric saw. The cubes aged 3, 7, 14, and 28 days were tested to find out their compressive strengths.

Simultaneously, steel molds of dimensions $15 \times 15 \times 15$ cm were filled with the same mixes, compacted, and cured under the same conditions. The cubes were examined to determine their compressive strengths. The number of all tests reached 232. Some representative results are presented in Fig. 6. It should be pointed out that all graphs, for different types of concrete mixes and different fabrics, have

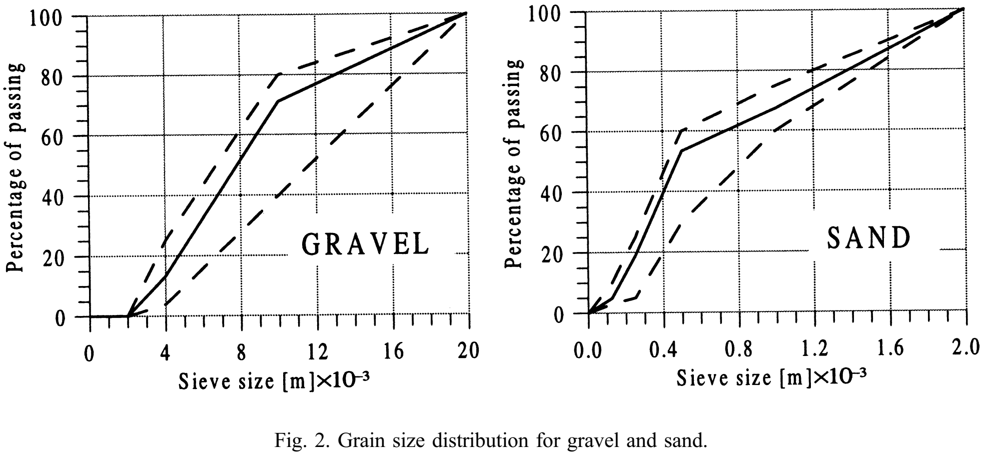

Fig. 2. Grain size distribution for gravel and sand.

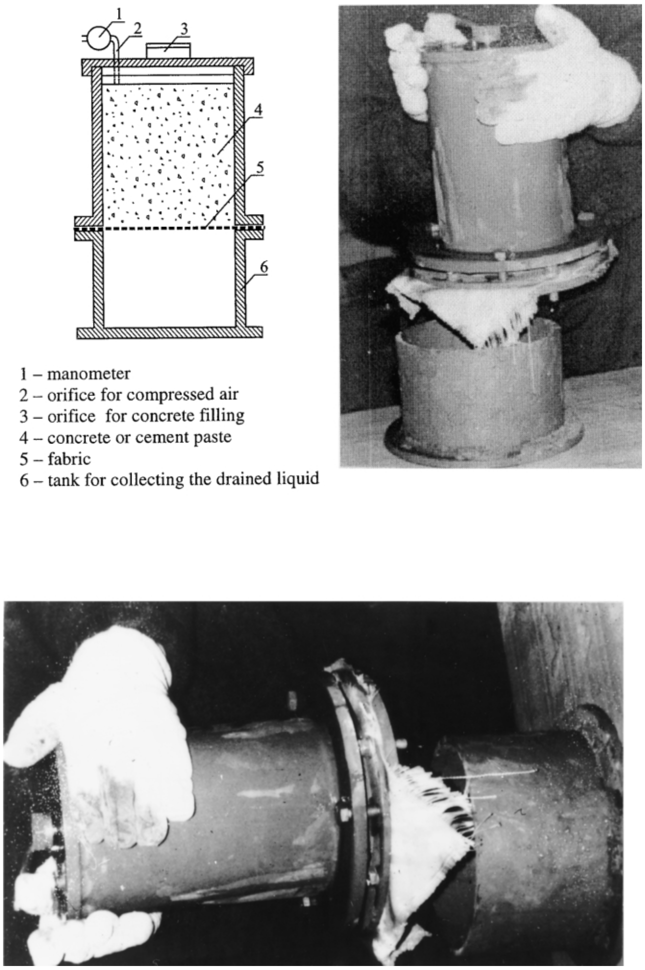

Fig. 3. Apparatus for fabric permeability test.

the same trend. For technical reasons, the size of the concrete cubes cast in steel molds and in fabric forms had different sizes. The comparison of the measured compressive strength has only informative meaning.

The analyses of the compressive tests showed the following.

(1) Sixty-five percent of the final compressive strengths of concrete cast in fabric forms was gained at an age of 3 days, about 85% at 7 days, and 95% at 14 days. The results for the same mixes in steel forms were 35%, 65%, and 85%, respectively. This could result from rapid setting of concrete when an excess of water drained out through the fabric.

(2) In general, the compressive strength of the concrete cast in fabric forms was a function of the pore size (mos) of the fabrics. In fabrics of moderate pores (0.35×10^{-3} m), it was possible to achieve the highest compressive strength. This could be attributed to the reduction of the w/c ratio before setting.

(3) The compressive strength decreased as the pore size of the fabric forms increased more than 0.35×10^{-3} m. In this mos, the compressive strength of concrete cast in fabric form was smaller than the concrete cast in steel molds. This could be assigned to the loss of the cement content as the pore size increased. The loss of cement could also be associated with the loss of very fine sand particles. It is not right to generalise the fact that concrete cast in fabric form is characterised by a higher compressive strength than the concrete cast in steel molds [19].

(4) The compressive strength of concrete decreased when the pore size of the fabric was very small (0.15×10^{-3} m). This could be explained by the clogging of the fabric pores and, consequently, free draining of water was difficult.

4.2. Statistical analysis

The obtained results are statistically analysed to estimate an equation for the final compressive strength of concrete cast in fabric forms.

The statistical analysis is performed by use of MINITAB program [20]. The program fits an equation for the experimental data by the least square method.

Table 4
The permeability test results: quantity of drained water, lost cement, and final w/c ratio

		PT/45 fabric			PT/48 fabric			PT/67s fabric			PT/67w fabric		
Sub mix	Initial w/c ratio	Drained water, [l] $\times 10^{-3}$	Lost cement, kg $\times 10^{-3}$	Final w/c	Drained water, [l] $\times 10^{-3}$	Lost cement, kg $\times 10^{-3}$	Final w/c	Drained water, [l] $\times 10^{-3}$	Lost cement, kg $\times 10^{-3}$	Final w/c	Drained water, [l] $\times 10^{-3}$	Lost cement, kg $\times 10^{-3}$	Final w/c
B3	0.64	65	3	0.58	153	25	0.52	185	176	0.57	201	253	0.6
B5	0.74	120	3	0.64	203	37.5	0.59	231	200	0.66	251	337.5	0.73
B6	0.82	154	3	0.69	275	48.5	0.62	278	237	0.73	300.5	405	0.85
C2	0.60	71	3	0.55	164	31	0.50	200	245	0.55	208	274	0.56
C4	0.72	130	4	0.63	217	46	0.59	260	256	0.65	272	377	0.71
C6	0.82	160	5	0.71	270	76	0.67	332	300	0.74	356	450	0.83
D2	0.57	69	2	0.53	162	36	0.48	212	279	0.53	224	283	0.52
D4	0.70	111	4	0.63	209	54	0.59	295	351	0.66	297	419	0.69
D6	0.83	149	5	0.74	274	71	0.7	375	370	0.78	376	478	0.84
E3	0.65	65	3	0.56	178	72	0.53	269	371	0.57	278	412	0.58
E5	0.70	91	4	0.65	244	94	0.60	340	426	0.67	374	429	0.68
E6	0.78	125	5	0.71	278	103	0.67	404	455	0.74	406	519	0.77

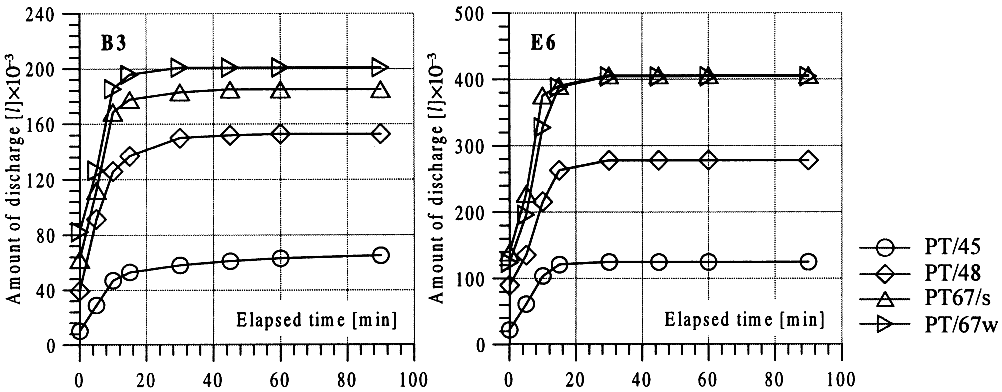

Fig. 4. The effect of fabric type (mos) on the amount of the discharged liquids for concrete mix B3 and E6.

The experimental data consist of compressive strength results related to cubes cut out of concrete mattresses cast in fabric forms. The number of observations equals $n = 232$. The independent variables are: w/c, water/cement ratio; q, the cement quantity [kg/m^3] (divided by 1000); and mos, the fabric microscopic opening size [m] $\times 10^{-3}$. After a complex statistical analysis, the following equation for a 28-day compressive strength f_c' is assumed:

$$f_c' = 15.34 - 33.65(\mathrm{w/c})^3 + 140.92q^3 + 275.2(\mathrm{mos}) - 625.4(\mathrm{mos})^2 + 367.72(\mathrm{mos})^3. \qquad (1)$$

To check the estimated equation, correlation coefficient ρ is calculated (Eq. (2)):

$$\rho = \frac{\sum_{i=1}^{n}(f'_{ci} - \hat{f}'_{ci})(\hat{f}'_{ci} - \bar{\hat{f}}'_{c})}{\sqrt{\sum_{i=1}^{n}(f'_{ci} - \bar{f}'_{c})^2 \sum_{i=1}^{n}(\hat{f}'_{ci} - \bar{\hat{f}}'_{c})^2}} = 0.9578 \qquad (2)$$

where $\hat{f}'_{ci} = \frac{1}{n}\sum_{i=1}^{n}\hat{f}'_{ci}$ denotes the mean value, n is the number of observations, $\hat{f}'_{ci}$ is the ith observation and $\hat{f}'_{ci}$ stands for the estimated ith observation. If $\rho = \pm 1$, the full correlation between f_{ci}' and $\hat{f}_{ci}$ is observed.

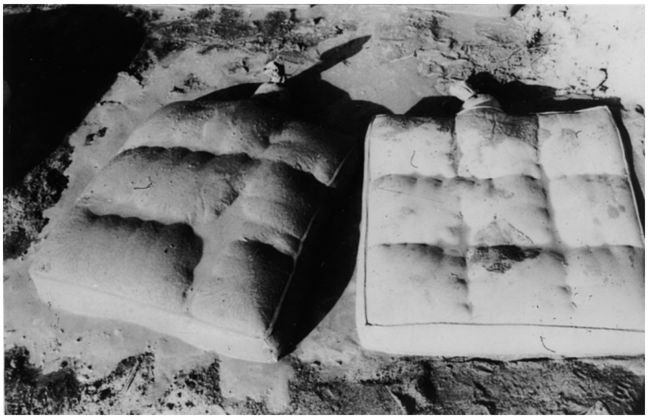

Fig. 5. Textile mattresses filled up with concrete mixes.

The mean square error (MSE) is calculated by making use of the following formula (Eq. (3)):

$$\mathrm{MSE} = \frac{\sum_{i=1}^{n}(f'_{ci} - \hat{f}'_{ci})^2}{n-k-1} = 8.75373 \qquad (3)$$

where $k = 3$ stands for the number of independent variables. The estimated standard deviation about the regression line s equals (Eq. (4)):

$$s = \sqrt{\mathrm{MSE}} = 2.95867. \qquad (4)$$

The 95% prediction interval of the ith observation (PI$_i$) is calculated according to the following formula (Eq. (5)):

$$\mathrm{PI}_i = \hat{f}'_{ci} \pm t_{0.05/2.232-2}s \qquad (5)$$

where $t_{0.05/2.31-2} = 1.96039$ is the constant taken from the Student's t distribution table. Frequency of the fitting of the estimated observations in the prediction interval is 96.98%.

A graphical interpretation of Eq. (1) is presented in Fig. 7.

An analysis of the obtained compressive strength, relation (1), proved that it estimates the test results correctly.

5. Discussion of the results and observations

In the work, a comprehensive analysis of synthetic fabrics and concrete elements cast in fabric forms is presented.

The permeability for 48 concrete mixes cast in four kinds of fabric forms was tested. The results indicate that the fabric formworks could be a solution to the problem of combining a sufficiently high workability with the minimum w/c ratios.

Concrete cast in fabric formworks is characterised by good quality. A comparison between the compressive strength of concrete cast in conventional molds and in fabric formworks showed that in fabrics with pore sizes ranging from 0.15×10^{-3} to 0.57×10^{-3} m, the strength

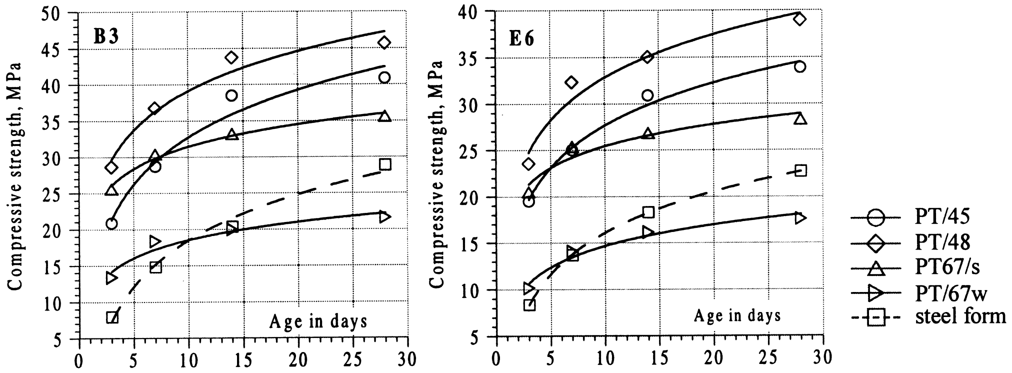

Fig. 6. Compressive strength vs. age in days for concrete mixes B3 and E6.

increased. For these kinds of concrete mixes, some lower w/c ratios were observed as an excess of water squeezed through the fabric. The maximum compressive strength was obtained for the fabric formwork of 0.35×10^{-3} m pore size. The comparative tests indicated also that it is not right to generalise the high compressive strength of concrete in fabric form in relation to the concrete in steel molds.

An equation for the compressive strength of concrete cast in fabric forms was statistically elaborated. It can be useful for designing purposes.

In fabrics of 0.68×10^{-3} m pore size, a maximum decrease of strength was observed. The lost cement and the very fine sand particles have a negative effect on the compressive strength. But in general, a decline of the compressive strength due to loss of cement may be compensated by a decrease of the w/c ratio. This kind of fabric presented the maximum adhesion between the concrete elements and secured their monolithic bond. For this reason, the fabric with $\text{mos} = 0.68 \times 10^{-3}$ m can be chosen as a material for designing column structures made of concrete elements cast in fabric formworks (see Refs. [11,13]).

References

[1] R.M. Koerner, J. Welsh, Fabric forms conform to any shape, Concr. Constr. Mag. 25 (5) (1980) 401–409.

[2] R. Silvester, Use of grout-filled sausages in coastal structures, J. Waterw., Port, Coastal Ocean Eng. 112 (1) (1986) 95–114.

[3] C. Barbagallo, S.J. Triano, High-tech landfill caps, Civil Eng. 1 (1993) 67–68.

[4] E. Brzeski, W. Robakiewicz, Design and construction of the stabilization of the ferry terminal sea-bed in Świnoujście by Ovolo mattress, Coastal Eng. Geotech. 3 (1993) 135–137.

[5] R.J. Bathurs, M.R. Simac, Geosynthetic reinforced segmental retaining wall structures in North America, Proceedings of 5th International Conference on Geosynthetics, Singapore, SEAC-IGS, vol. 4, (1994) 31–54.

[6] W. Monnet, Concrete mats in hydraulic engineering and experience, 4th International Conference on Geotextiles, Geomembranes and Related Products, The Hague, Netherlands, vol. 1, (1990) 412.

[7] R. Nicholls, Construction of grout-impregnated fabric-reinforced pipes, J. Constr. Eng. Manage. 118 (2) (1992) 283–302.

[8] Fabriform — Unimat Fabric Styles, Erosion Control Revetments, Construction Techniques, U.S. Patent Nos. 396,545 and 3,811,480.

[9] M. Schupack, Three Dimensionally Reinforced Fabric Concrete, U.S. Patent No. 4,617,219.

[10] J.P. Welsh, Synthetic fabrics as concrete-forming device, 2nd International Conference on Geotextiles, Las Vegas, USA.

[11] M.S. Al Awwadi Ghaib, Technology and Design of Concrete Elements Cast in Fabric Formworks, PhD Dissertation, Technical University of Gdańsk, Poland, 1996.

[12] M.S. Al Awwadi Ghaib, Concrete in fabric forms, Civil Eng. 12 (1994) 570–571 (in Polish).

[13] M.S. Al Awwadi Ghaib, J. Górski, Statistical analysis of model testing of concrete elements in fabric formworks, 2nd International Conference Analytical Models and New Concepts in Mechanics of Concrete Structures, Łódź, Poland, 1997.

[14] J. Górski, M.S. Al Awwadi Ghaib, Compressive strength of concrete

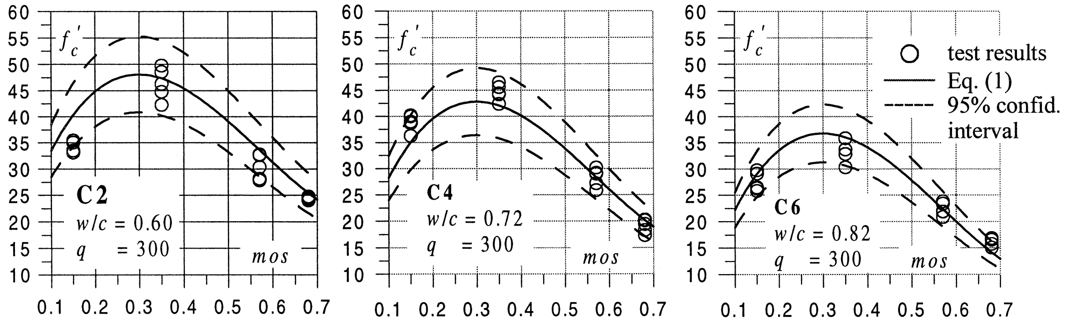

Fig. 7. Graphical interpretation of Eq. (1) for concrete mix C2, C4, and C6.

cast in fabric forms, 5th International Conference Modern Building Materials, Structures and Technologies, Vilnius, Lithuania, vol. 1, (1997) 27–32.

[15] Polish Standard Code No. PN-75/C-89058, Fabrics, Tensile Strength Tests.

[16] Polish Standard Code No. PN-88/B-04301, Cement — Testing Methods.

[17] Polish Standard Code No. PN-87/B-06721, Aggregate, Specimen Testing.

[18] J. Mlynarek, J. Lafleur, A. Rollin, G. Lombard, Filtration opening size of geotextiles by hydrodynamic sieving, Geotech. Test. J. 16 (1) (1993) 61–69.

[19] B. Lamberton, Fabric forms for erosion control and pile jacketing, Concr. Constr. Mag. 25 (5) (1980) 395–399.

[20] R.L. Schaefer, R.B. Anderson, The Students' Edition of MINITAB Statistical Software Adapted for Education, Addison-Wesley Publishing, USA, 1989.