EAN 2017
55th conference on experimental stress analysis

Influence of Temperature on Selected Mechanical Properties of Geopolymer Composites

Jan Krystek[1,a], Vladislav Laš[2,b], Vilém Pompe[3,c] and Pavlína Hájková[4,d]

[1,2,3] European Centre of Excellence, NTIS – New Technologies for Information Society, University of West Bohemia, Univerzitní 8, 301 00 Plzeň, Czech Republic

[4]Unipetrol Centre for Research and Education a.s., Revoluční 1521/84, 400 01 Ústí nad Labem, Czech Republic

[a]krystek@kme.zcu.cz, [b]las@kme.zcu.cz, [c]pompe@ntis.zcu.cz, [d]pavlina.hajkova@unicre.cz

Keywords: Bending; Composite; Geopolymer; Temperature conditioning; Tension.

Abstract. The composites with polymer matrix cannot be used in high temperature environment, while geopolymers excel in high temperature resistance. This paper presents analysis of influence of temperature conditioning on selected mechanical properties of geopolymer composites. Prismatic specimens with two types of geopolymer matrix were tested in tensile or bending tests. The dependencies of the selected mechanical properties on the temperature conditioning were identified for both types of geopolymer matrix.

Introduction

Currently, composite materials are applied in many industrial areas. It is due to their very good mechanical properties, for example low weight, high strength and high stiffness. Usually, these composites are made with carbon or glass fibers and polymer matrix, for example epoxy matrix. A disadvantage of these composites is that they cannot be used in high temperatures, because their mechanical properties significantly degrade with increasing temperature. This shortcoming can be removed using a geopolymer matrix. Geopolymer matrix is an inorganic polymer material. Preparation of this material is based on aluminosilicate alkali activation. The bond Si-O-Al-O is formed by the polymerization usually under normal temperature and pressure. Geopolymers excel in many properties, primarily high temperature resistance [1, 2], frost resistance or resistance against acids and organic solvent agents. The temperature resistant matrix does not have good mechanical properties such as strength, stiffness or impact resistance, therefore fiber reinforcement is used in order to improve these properties [3-7].

The paper presents analysis of variation of mechanical properties of geopolymer composite with carbon fibers subjected to high temperature. Two types of geopolymer matrix were used. Tensile and bending tests were performed for identification of mechanical properties.

Materials and specimens

Carbon fibers (Table 1) and two types of geopolymer matrix were used in this work. Geopolymer matrix FC4 consists of potassium water glass, potassium hydroxide (KOH), silica fume, material with high content of metakaolinite, and boric acid. Molar ratios of the components are presented in Table 2. Geopolymer matrix B3P1 consists of potassium water glass, material with high content of metakaolinite, and ingredients with calcium. Material with metakaolonite Mefisto L_{05} (produced by České lupkové zavody, a.s.) was used for both types of matrix.

Table 1: Properties of carbon fabric.

Material of fibers	**Binding**	**Area weight**	**Thickness**	**Density**
Toray 3K 200 tex	plain	200 [g/m^2]	0.32 [mm]	1 760 [kg/m^3]

Table 2: Molar ratios.

	alkali activator modulus (SiO_2/M_2O)	Si:Al	M:Al	Ca:Al	H_2O:Al
FC4	1.08	17.07	4.35	-	24.62
B3P1	1.56	1.80	1.00	0.12	6.01

The composite plates were made from 10 layers of plain weave carbon fabric (200 g/m^2). The prismatic specimens were cut using diamond blade. The specimens were subjected to conditioning temperature at 23 °C, 200 °C, 400 °C or 600 °C. Afterwards, the tensile or bending tests were performed using universal testing machine *Zwick/Roell Z050* at room temperature. Designation of specimens is presented in Fig. 1.

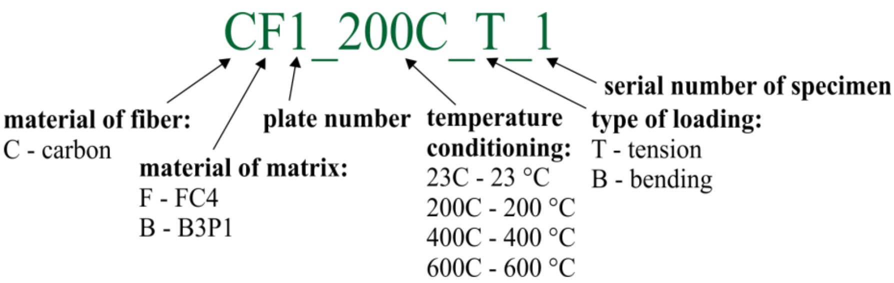


Fig 1: Designation of specimens.

Tensile test

The force–displacement dependencies were obtained from tensile test complying with *ASTM D 3039*. The specimen size was modified according to possibilities resulting from the plate size. Total length of the tensile specimens was $l_c = 150$ mm. An initial grip distance was $l_j = 100$ mm. An extensometer was used for measuring the displacement (gage length was $l_e = 60$ mm). The geometric parameters of specimens (width W, thickness H, weight M and fiber volume ratio V_f) are presented in Table 3. The load velocity (crosshead displacement) was $v_T = 2$ mm/min.

The specific load capacity–strain dependencies were calculated. The specific load capacity f is the load, which is carried by one layer of fibers having a width of one meter

$$f = \frac{F_{\max}}{W \cdot n_L}, \tag{1}$$

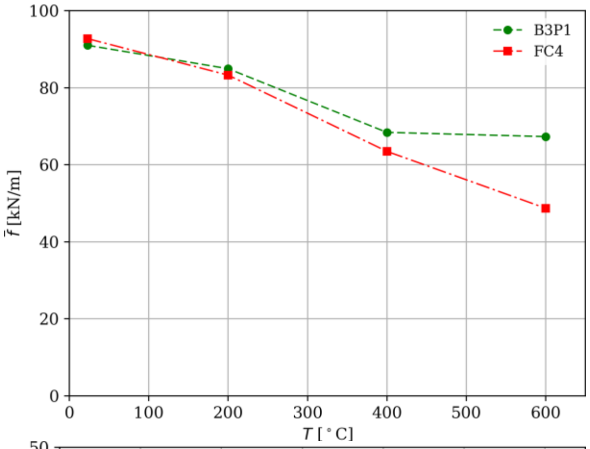
where $F_{\max}$ is maximum force, W is width of specimen and n_L is number of fiber layers in specimen. Values of maximum force $F_{\max}$, maximum tensile stress ($\sigma_{\max} = F/(W \cdot H)$), strain for maximum tensile stress $\varepsilon_{\max}$, specific load capacity f and effective moduli E are presented in Table 4. The effective moduli was identified on interval of strain $\varepsilon \in \langle 0.0005, 0.001 \rangle$. The dependencies of the specific load capacity on temperature conditioning are shown in Fig. 2 for both types of the geopolymer matrix. The dependencies of the effective moduli on temperature conditioning are shown in Fig. 3.

Table 3: Weight, geometric parameters and fiber volume ratio of tensile specimens.

specimen	W [mm]	H [mm]	M [g]	V_f [%]	specimen	W [mm]	H [mm]	M [g]	V_f [%]
CF1_23C_T_1	25.7	2.9	18.45	39.2	CB4_23C_T_1	25.9	3.5	18.76	32.5
CF1_23C_T_2	25.7	3.0	18.74	37.9	CB4_23C_T_2	25.7	3.6	18.57	31.6
CF1_23C_T_3	25.9	3.0	19.92	37.9	CB4_23C_T_3	26.2	3.7	19.28	30.7
CF1_200C_T_1	25.7	2.9	18.19	39.2	CB4_200C_T_1	25.9	3.6	18.66	31.6
CF1_200C_T_2	25.8	2.9	18.65	37.9	CB4_200C_T_2	26.0	3.6	19.03	31.6
CF1_200C_T_3	25.7	3.0	18.95	37.9	CB4_200C_T_3	26.1	3.6	19.02	31.6
CF1_400C_T_1	26.2	3.0	19.53	36.7	CB4_400C_T_1	26.2	3.6	19.19	31.6
CF1_400C_T_2	25.9	3.1	20.08	37.9	CB4_400C_T_2	26.2	3.7	19.63	30.7
CF1_400C_T_3	25.9	3.0	19.79	37.9	CB4_400C_T_3	25.8	3.6	19.12	31.6
CF1_600C_T_1	25.7	3.0	19.17	37.9	CB4_600C_T_1	25.9	3.6	19.11	31.6
CF1_600C_T_2	26.0	3.0	19.53	37.9	CB4_600C_T_2	25.7	3.5	18.58	32.5
CF1_600C_T_3	26.0	3.0	19.30	37.9	CB4_600C_T_3	25.7	3.5	18.32	32.5

Table 4: Maximum force, stress and strain, specific load capacity and effective tensile moduli.

specimen	F_{max} [N]	σ_{max} [MPa]	ε_{max} [%]	f [kN/m]	$\bar{f}$ [kN/m]	E [GPa]	$\bar{E}$ [GPa]
CF1_23C_T_1	19388	260.1	1.00	94.3		44.9	
CF1_23C_T_2	17354	225.1	0.94	84.4	92.77	41.0	42.67
CF1_23C_T_3	20631	265.5	1.10	99.6		42.1	
CF1_200C_T_1	17553	235.5	1.01	85.4		38.6	
CF1_200C_T_2	17175	229.5	1.05	83.2	83.30	36.4	37.47
CF1_200C_T_3	16707	216.7	0.91	81.3		37.4	
CF1_400C_T_1	15001	190.9	0.99	71.6		25.0	
CF1_400C_T_2	11773	146.6	0.92	56.8	63.50	20.0	21.83
CF1_400C_T_3	12861	165.5	0.94	62.1		20.5	
CF1_600C_T_1	10227	132.6	0.70	49.7		25.6	
CF1_600C_T_2	9918	127.2	0.58	47.7	48.73	28.6	25.97
CF1_600C_T_3	10159	130.2	0.64	48.8		23.7	
CB4_23C_T_1	19147	211.2	1.23	92.4		19.2	
CB4_23C_T_2	18520	198.6	1.08	89.4	91.03	21.3	19.47
CB4_23C_T_3	18769	197.4	1.12	91.3		17.9	
CB4_200C_T_1	17769	190.6	1.13	85.8		19.2	
CB4_200C_T_2	17461	186.6	1.09	83.9	84.97	16.8	18.57
CB4_200C_T_3	17799	189.4	1.08	85.2		19.7	
CB4_400C_T_1	14092	149.4	0.86	67.2		10.3	
CB4_400C_T_2	14707	151.7	0.90	70.2	68.43	10.3	9.97
CB4_400C_T_3	14015	150.9	1.13	67.9		9.3	
CB4_600C_T_1	14120	151.4	1.07	68.1		9.0	
CB4_600C_T_2	13770	154.3	1.05	67.5	67.33	8.0	8.30
CB4_600C_T_3	13590	151.1	1.01	66.1		7.9	



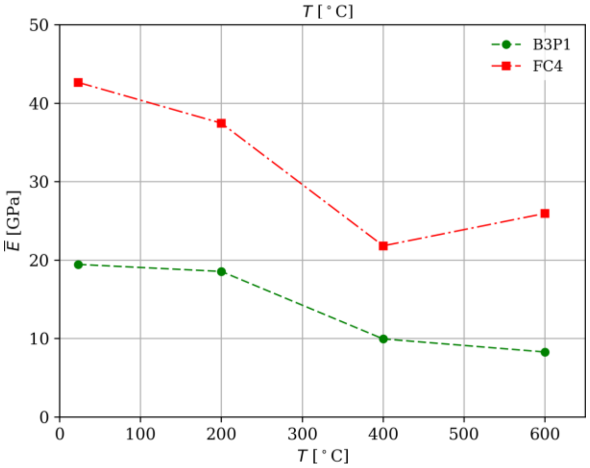


Fig. 2: Dependencies of the specific load capacity on temperature conditioning.

Fig. 3: Dependencies of the effective moduli on temperature conditioning.

Bending test

The force–displacement dependencies were obtained from bending test complying with *ČSN EN 2562*. Total length of the tensile specimens was $l_c = 150$ mm. The support span was $l_s = 80$ mm. An extensometer was used for measuring the displacement of loading nose. The geometric parameters of specimens (width W, thickness H), weight M and fiber volume ratio V_f are presented in Table 5. The load velocity (crosshead displacement) was $v_B = 5$ mm/min.

Table 5: Weight, geometric parameters and fiber volume of bending specimens.

specimen	W [mm]	H [mm]	M [g]	V_f [%]	specimen	W [mm]	H [mm]	M [g]	V_f [%]
CF1_23C_B_1	26.1	3.0	19.44	37.9	CB4_23C_B_1	25.6	3.5	18.58	32.5
CF1_23C_B_2	25.7	2.8	17.74	40.6	CB4_23C_B_2	25.6	3.5	18.75	32.5
CF1_23C_B_3	25.7	2.8	17.20	40.6	CB4_23C_B_3	25.8	3.5	18.72	32.5
CF1_200C_B_1	25.8	2.9	19.02	39.2	CB4_200C_B_1	25.7	3.5	18.80	32.5
CF1_200C_B_2	25.9	2.9	18.51	39.2	CB4_200C_B_2	26.2	3.6	19.05	31.6
CF1_200C_B_3	25.8	2.8	17.96	40.6	CB4_200C_B_3	25.9	3.6	18.84	31.6
CF1_400C_B_1	26.0	2.8	18.19	40.6	CB4_400C_B_1	25.8	3.6	18.85	31.6
CF1_400C_B_2	26.1	2.8	18.74	40.6	CB4_400C_B_2	26.0	3.6	19.33	31.6
CF1_400C_B_3	26.0	2.9	17.53	39.2	CB4_400C_B_3	26.2	3.6	19.43	31.6
CF1_600C_B_1	26.1	2.9	19.39	39.2	CB4_600C_B_1	25.9	3.6	19.13	31.6

CF1_600C_B_2	26.1	2.9	18.94	39.2	CB4_600C_B_2	25.8	3.5	18.31	32.5
CF1_600C_B_3	26.1	2.9	19.15	39.2	CB4_600C_B_3	26.2	3.6	19.35	31.6

Values of maximum force F_{max}, maximum tensile stress

$$\sigma_{max} = \frac{3 \cdot F_{max} \cdot l_s}{2 \cdot W \cdot H^2}, \qquad (2)$$

and displacement for maximum force are presented in Table 6. The dependencies of the maximum stress on temperature conditioning is shown in Fig. 4 for both types of the geopolymer matrix. Experimental setup and typical failure after the bending test is shown in Fig. 5.

Table 6: Maximum force, maximum stress and displacement for maximumforce - bending.

specimen	F_{max} [N]	σ_{max} [MPa]	$\overline{\sigma_{max}}$ [MPa]	u_{max} [mm]	specimen	F_{max} [N]	σ_{max} [MPa]	$\overline{\sigma_{max}}$ [MPa]	u_{max} [mm]
CF1_23C_B_1	210	107.4		2.05	CB4_23C_B_1	136	52.2		1.32
CF1_23C_B_2	194	115.7	116.47	2.37	CB4_23C_B_2	146	55.8	53.57	2.02
CF1_23C_B_3	212	126.3		2.40	CB4_23C_B_3	139	52.7		1.57
CF1_200C_B_1	170	93.8		2.61	CB4_200C_B_1	77	29.2		1.69
CF1_200C_B_2	164	90.2	92.73	1.90	CB4_200C_B_2	79	27.8	28.07	1.56
CF1_200C_B_3	159	94.2		1.90	CB4_200C_B_3	76	27.2		1.76
CF1_400C_B_1	123	72.4		1.83	CB4_400C_B_1	35	12.7		2.76
CF1_400C_B_2	136	79.9	72.8	2.37	CB4_400C_B_2	40	14.1	13.43	2.15
CF1_400C_B_3	120	66.1		1.68	CB4_400C_B_3	38	13.5		1.67
CF1_600C_B_1	200	109.2		1.66	CB4_600C_B_1	31	11.2		1.58
CF1_600C_B_2	192	104.9	108.37	1.74	CB4_600C_B_2	29	11.1	11.23	1.44
CF1_600C_B_3	203	111.0		1.76	CB4_600C_B_3	32	11.4		1.57

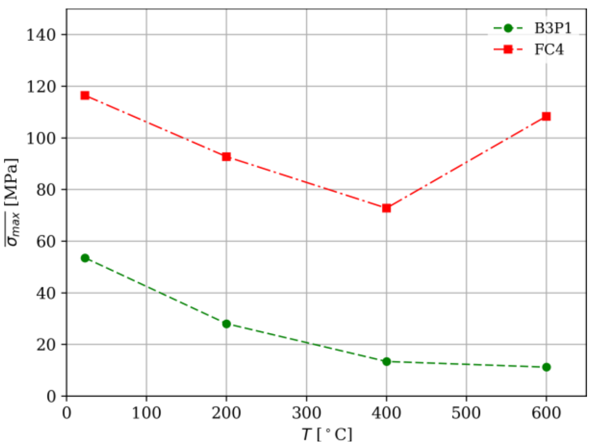


Fig. 4: Dependencies of the maximum stress on temperature conditioning – bending test.

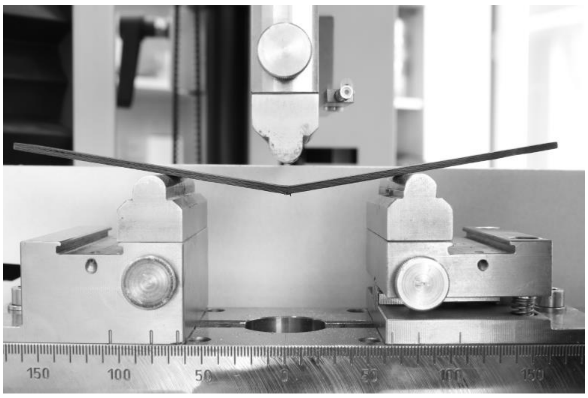


Fig. 5: Typical failure after bending test.

Conclusion

The composite specimens were composed of carbon fibers and geopolymer matrix. Two types of geopolymer matrix were used. The specimens were subjected to conditioning temperature at 23 °C, 200 °C, 400 °C or 600 °C. Afterwards the tensile or bending tests were performed at room temperature.

The dependence of the specific load capacity and the effective moduli on the conditioning temperature were determined in case of tensile test. The specific load capacity decreases with increasing temperature conditioning for both types of geopolymer matrix. The effective moduli in tension for the specimens with matrix B3P1 is approximately half that for the specimen with FC4 matrix.

In case of bending test, maximum stress for the specimens with matrix B3P1 is lower than for the specimen with FC4 matrix. The maximum stress decreases with increasing conditioning temperature for matrix B3P1. In case of matrix FC4, the maximum stress decreases with increasing conditioning temperature only up to 400 °C.

Acknowledgment

This publication was supported by the project LO1506 of the Czech Ministry of Education, Youth and Sports. The publication is a result of the project Development of the UniCRE Centre (project code LO1606) which was financially supported by the Ministry of Education, Youth and Sports of the Czech Republic under the National Programme for Sustainability I.

References

[1] C. Papakonstantinou, P. Balaguru, R.Lyon, Comparative study of high temperature composites, Composites Part B: Engineering 32 (8) (2001) 637-649.

[2] J. Mills-Brown, K. Potter, S. Foster, T. Batho, Thermal and tensile properties of polysialate composites, Ceramics International 39 (2013) 8917-8924.

[3] D. Pernica, P. Reis, J. Ferreira, P. Lauda, Effect of test condition on bending strength of geopolymer-reinforced composite, J Mater Sci (2010) 45:744-749.

[4] M. Alzeer, K. MacKenzie, Synthesis and mechanical properties of novel composites of inorganic polymers (geopolymers) with unidirectional natural flax fibers (phormium tenax), Applied Clay Science 75-76 (2013) 148-152.

[5] A. Natali, S. Manzi, M. Bignozzi, Novel fiber-reinforced composite materials based on sustainable geopolymer matrix, Procedia Engineering 21 (2011) 1124-1131.

[6] S. Samal, B. Marvalová, I. Petriková, K. Vallons, S. Lomov, H. Rahier, Impact and post impact behavior of fabric reinforced geopolymer composite, Construction and Building Materials 127 (2016) 111-124.

[7] S. Samal, et al. Impact and post impact behavior of fabric reinforced geopolymer composite. Construction and Building Materials, 2016, 127: 111-124