Tensile and bending test of carbon/epoxy and carbon/geopolymer composites after temperature conditioning

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Abstract. Composites with epoxy matrix cannot be used in high temperature, while geopolymer matrix excel in high temperature resistance. First, prismatic specimens were subjected to conditioning temperature. Second, the tensile and bending test were performed at room temperature. This paper present comparison of mechanical properties of carbon/epoxy and carbon/geopolymer composites. Numerical simulations of tensile and bendidng tests were performed in finite element system Abaqus.

Keywords: bending test; composite; geopolymer; numerical simulation; tensile test.

1 Introduction

Currently, composite materials are applied in many industrial areas. Usually, composites are made with carbon or glass fibers and epoxy matrix. These composites have very good mechanical properties, for example low weight, high strength and high stiffness, but they cannot be used in high temperature environments. Mechanical properties of these composites 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. Geopolymers excel in many properties. Generally, the papers present high temperature resistance [1 – 5] or resistance against acids and organic solvent agents. Any paper, which present specific mechanical properties of carbon/geopolymer composites, was not found.

This paper presents analysis of mechanical properties of carbon/epoxy and carbon/geopolymer composites. Composites with geopolymer matrix were subjected to high temperature. Two types of geopolymer matrix were used. Tensile and bending test were performed for identification of mechanical properties. Numerical simulations of these tests were performed in finite element system Abaqus.

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2 Materials and specimens

The composites plates were made from 10 layers of plain weave carbon fabric (Table 1). The prismatic specimens were cut using diamond blade. Epoxy matrix L285 and hardener 285 MGS was used for specimens with label CE1. Two types of geopolymer matrix were used in this work. Geopolymer matrix FC4 consists of potassium water glass, potassium hydroxide (KOH), silica fume, constituent 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, constituent with high content of metakaolinite, and ingredients with calcium. Constituent with metakaolonite Mefisto L_{05} (produced by České lupkové zavody, a.s.) was used for both types of geopolymer 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 specimens with geopolymer matrix were subjected to conditioning temperature of 23 °C, 200 °C, 400 °C or 600 °C, specimens with epoxy matrix only of 23 °C. Temperature resistance of the used epoxy matrix is lower than 200 °C. Afterwards, the tensile or bending test were performed using universal testing machine *Zwick/Roell Z050* at room temperature. Designation of specimens is presented in Fig. 1.

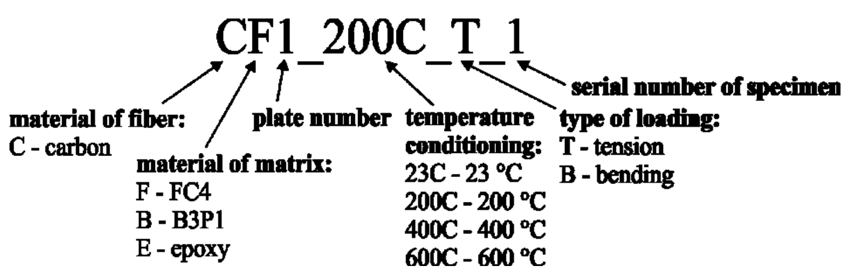

Fig. 1. Designation of specimens

The geometric properties of all specimens with epoxy matrix were: width W_e = 25 mm, thickness H_e = 2.4 mm, total length L_e = 180 mm. The geometric properties of specimens with geopolymer matrix were: width W_g = 25÷26 mm, thickness H_g = 2.9÷3.6 mm, total length L_g = 150 mm. The exact dimensions for each specimen are given in [5].

3 Tensile test

The force–displacement (F–Δl) dependencies were obtained from tensile test complying with ASTM D 3039. The specimen size was modified according to possibilities resulting from the plate size. An initial grip distance was l_j = 100 mm. An extensometer was used for measuring the elongation. Gage length was $l_e = 60$ mm. The load velocity (crosshead displacement) was $v_T = 2$ mm/min.

The stress-strain dependencies were calculated using

$$\sigma = \frac{F}{W \cdot H}\,, \qquad \varepsilon = \frac{\Delta l}{l_e}\,, \tag{1}$$

where F is loading force, W is width of specimen, H is thickness of specimen, Δl is elongation and l_e is initial gage length. The effective modulus was identified according to the standard *ASTM D 3039* on interval of strain $\varepsilon \in \langle 0.1\%, 0.3\% \rangle$. The stress–strain dependencies of CB4 and CF1 specimens for all temperature conditioning are shown in Fig. 2 and Fig. 3, for CE1 specimens at 23 °C in Fig. 4. The values of maximum stress and effective modulus are presented in Table 3 and Table 4.

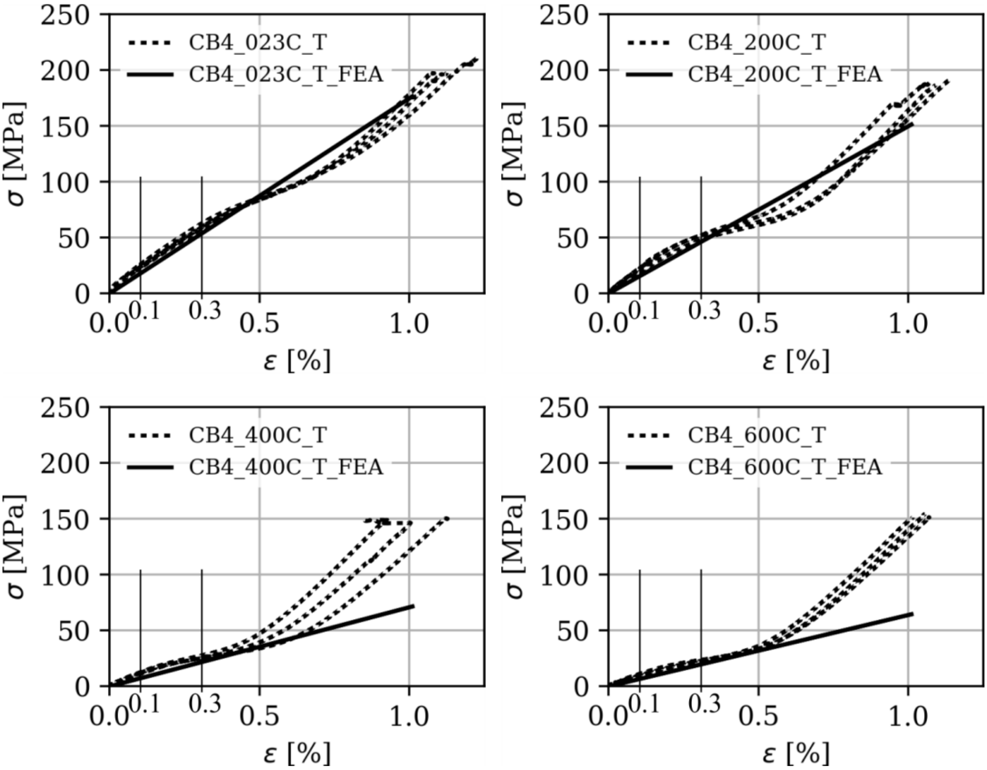

Fig. 2. Stress–strain dependencies for CB4 specimens

Table 3. Maximum stress, effective modulus and averaged modulus for CE1 specimens

specimen	σ_{max} [MPa]	E [GPa]	$\overline{E}$ [GPa]
CE1_23C_T_1	537.9	53.5	
CE1_23C_T_2	581.6	54.7	53.67
CE1_23C_T_3	510.2	52.8	

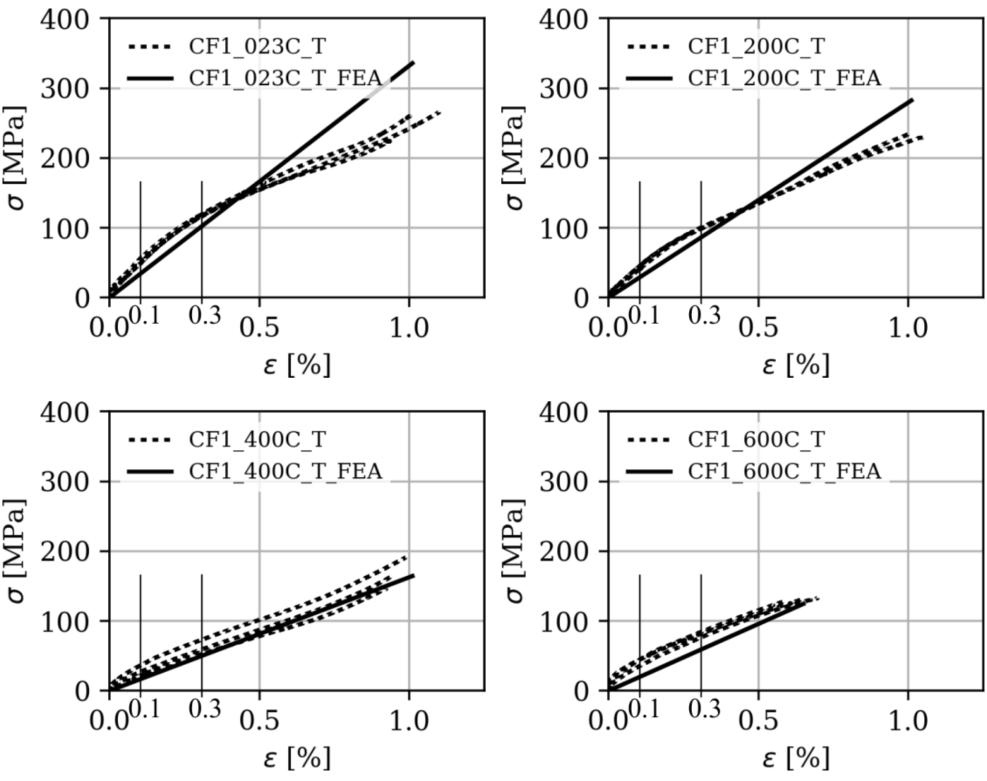

Fig. 3. Stress–strain dependencies for CF1 specimens

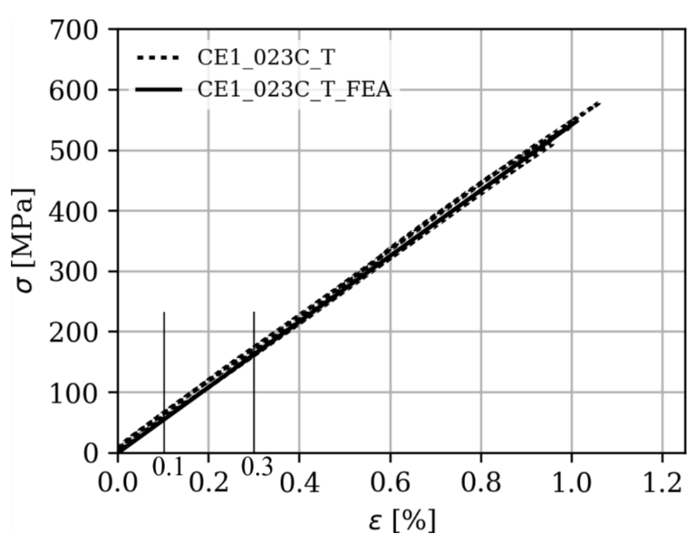

Fig. 4. Stress–strain dependencies for CE1 specimens

The stress–strain dependencies are linear for specimens with epoxy matrix and they are nonlinear for specimens with geopolymer matrix. The effective modulus in tension for CB4 specimens with B3P1 geopolymer matrix is approximately half that of the CF1 specimen with FC4 geopolymer matrix. The effective modulus in tension of CE1 specimen with epoxy matrix is larger by 60% that of CF1 specimen for 23 °C temperature conditioning.

Table 4. Maximum stress, effective modulus and averaged modulus CB4 and CF1 specimens

specimen	σ_{max} [MPa]	E [GPa]	$\overline{E}$ [GPa]	specimen	σ_{max} [MPa]	E [GPa]	$\overline{E}$ [GPa]
CB4_23C_T_1	211.2	17.3		CF1_23C_T_1	260.1	31.8	
CB4_23C_T_2	198.6	18.1	17.50	CF1_23C_T_2	225.1	33.8	33.27
CB4_23C_T_3	197.4	17.1		CF1_23C_T_3	265.5	34.2	
CB4_200C_T_1	190.6	15.4		CF1_200C_T_1	235.5	27.0	
CB4_200C_T_2	186.6	14.6	15.00	CF1_200C_T_2	229.5	29.5	28.03
CB4_200C_T_3	189.4	15.0		CF1_200C_T_3	216.7	27.6	
CB4_400C_T_1	149.4	6.6		CF1_400C_T_1	190.9	17.9	
CB4_400C_T_2	151.7	7.5	7.13	CF1_400C_T_2	146.6	15.3	16.30
CB4_400C_T_3	150.9	7.3		CF1_400C_T_3	165.5	15.7	
CB4_600C_T_1	151.4	6.4		CF1_600C_T_1	132.6	20.0	
CB4_600C_T_2	154.3	6.1	6.40	CF1_600C_T_2	127.2	19.2	19.20
CB4_600C_T_3	151.1	6.7		CF1_600C_T_3	130.2	18.4	

3.1 Numerical simulation of the tensile test

The finite element system *Abaqus* was used for the numerical simulation of the tensile test. Quadratic hexahedral elements with 20 nodes were used in a parametrically created model (Fig. 5). The loading was controlled by the displacement of the upper crosshead. One numerical model was created for each group of specimens (material of matrix + temperature conditioning). This model had averaged geometric parameters. Isotropic material model with average effective modulus (Table 2) was used in numerical analysis. The stress–strain dependencies obtained using finite element analysis (FEA) are presented in Fig. 2 – Fig. 4.

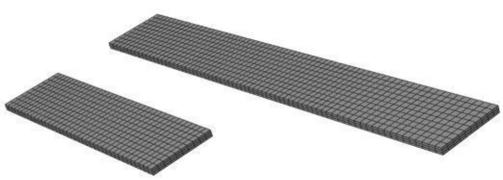

Fig. 5. Finite element model – tension (left) and bending (right)

4 Bending test

The force–displacement (F–Δl) dependencies were obtained from 3-point bending test complying with ASTM D 7264. The support span was $l_s = 80$ mm. An extensometer was used for measuring the displacement of loading nose (deflection of specimen). The load velocity (crosshead displacement) was $v_B = 2$ mm/min.

4.1 Numerical simulation of the bending test

The finite element system Abaqus was used for the numerical simulation of the bending test. Quadratic hexahedral elements with 20 nodes were used in a parametrically created model One numerical model was created for each group of specimens (material of matrix + temperature conditioning). This model had averaged geometric parameters. Isotropic material model with average effective modulus (Table 2) was used in numerical analysis. The force–displacement dependencies obtained using finite element model are presented in Fig. 6 - Fig. 8.

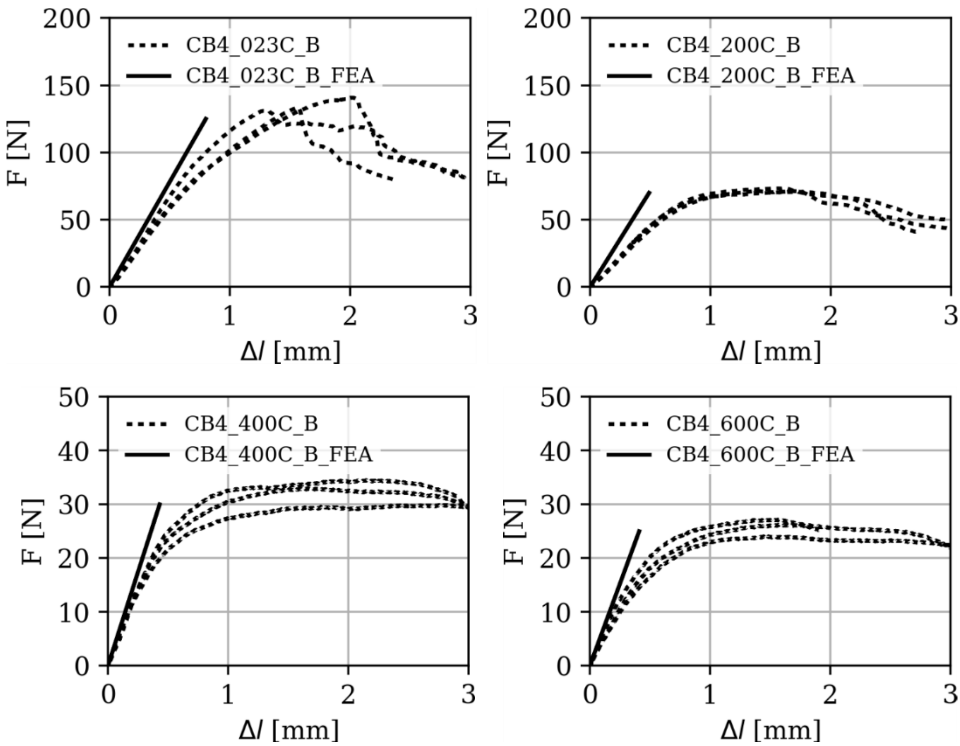

Fig. 6. Force–displacement dependencies for CB4 specimens

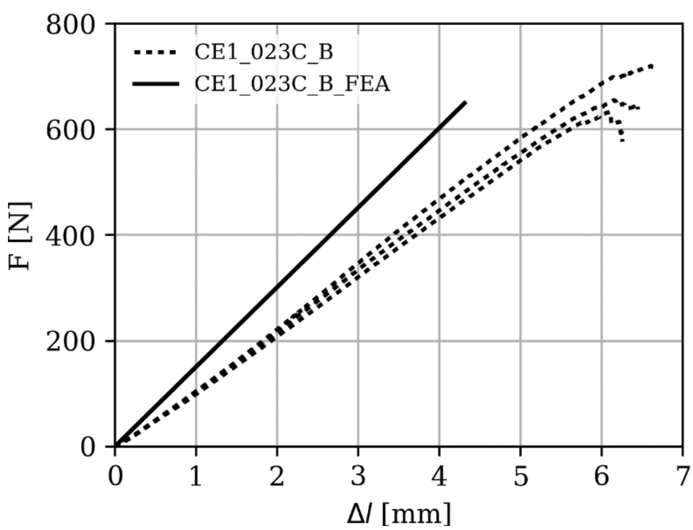

Fig. 7. Force–displacement dependencies for CE1 specimens

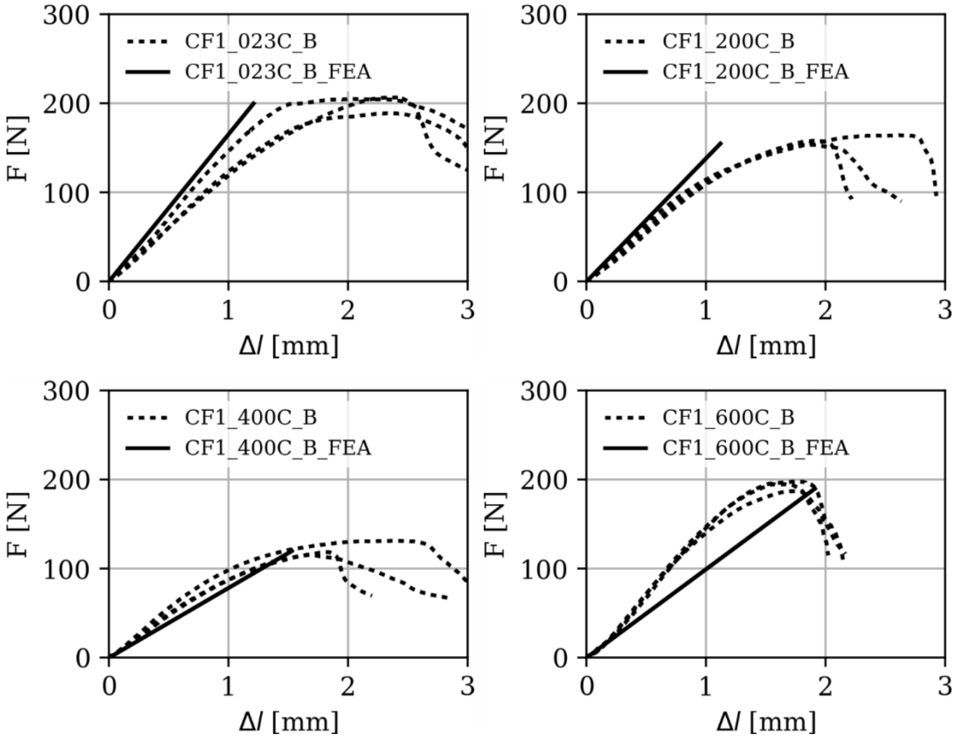

Fig. 8. Force–displacement dependencies for CF1 specimens.

Conclusion

The composite specimens were composed of carbon fibers and geopolymer or epoxy 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 numerical simulation of tensile and bending tests were performed in finite element system Abaqus.

The stress-strain dependencies were calculated for tensile test. The stress-strain depedencies are linear for specimens with epoxy matrix and they are nonlinear for specimens with geopolymer matrix. The effective modulus in tension for CB4 specimens with B3P1 geopolymer matrix is approximately half that of the CF1 specimen with FC4 geopolymer matrix. The effective modulus in tension of CE1 specimen with epoxy matrix is larger by 60% that of CF1 specimen for 23 °C temperature conditioning.

In case of bending test, the force-displacement dependencies were obtained from 3-point bending test. The effective modulus in tension was used in numerical simulation of bending tests. These numerical models showed higher stiffness than the experiment.

The multilayer composites show different value of the effective elasticity modulus for tension and bending. Therefore, in the 3D solid finite element model, the effective elasticity for bending has to be used in the 3 point bending model.

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