COMPOSITE BASED ON GEOPOLYMER MORTAR REINFORCED CHOPPED BASALT FIBER AND CARBON TEXTILE

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Abstract: *This paper deals with the evaluation of the four-point bending strength of geopolymer composite thin plates, which made of carbon grid embedded in geopolymer mortar containing various contents of chopped basalt fiber. Sodium-based geopolymer binder along with silica sand and chopped basalt fiber (0%, 3%, 5%, 7.5% by weight of geopolymer resin) are mixed together to make fresh geopolymer mortar. Then thin-plate specimens with the dimension 400x100x15 mm^3 (length, wide, thickness) are produced by using one-layer of carbon grid embedded in fresh geopolymer mortar. The specimens were tested at a time period of approximately 28 days after casting. The tested results show that the increase in the chopped fiber percentage improves flexural strength (both at first-crack and peak load) of geopolymer composite thin plates.*

Keywords: *Geopolymer, four-point flexural strength, geopolymer mortar, carbon textile, chopped basalt fiber.*

1 INTRODUCTION

Geopolymers are inorganic polymer materials with a chemical composition similar to natural zeolite but containing an amorphous microstructure and possessing ceramic-like in their structures and properties. Geopolymers are formed by reacting an alumino-silicate rich source (metakaolin, fly ash or nature pozzolanic, etc.) with an alkaline solution of the balancing cation of choice. Their amorphous structure composed of cross-linked alumina (AlO_4^-) and silica (SiO_4) tetrahedra to form polysialates, with an alkali metal ion to balance with the negative charge [1-4]. Geopolymers have recently emerged as novel engineering binder materials with environmentally sustainable properties. The reduced energy consumption and CO_2 emission during manufacture make them attractive alternative over Portland cement [5, 6].

Textile-reinforced concrete (TRC) is a new composite material composed of a fine-grained matrix with textile materials such as alkali-glass, carbon, basalt or polymer alternative to usual steel reinforced bars [7]. The major advantages of TRC are its high tensile strength and pseudo-ductile due to its tolerance of multiple cracking. Furthermore, such textile-reinforcement has the ability to withstand corrosion, aggressive environments and therefore does not require a strong covering layer in contrast to steel reinforced concrete, where requires sufficient thickness of the concrete layer to protect the corrosion of steel-reinforcement during the lifetime of the structure [8]. Therefore, it is resulting in thinning and reduction of the mass of the whole structure. Thanks to their excellent material properties, the TRC composite is used in a wide range of application such as thin-walled elements, repairing and/or strengthening in structural elements, façade elements, bridges and also freeform and lightweight structures [9-13]. The textile in composite materials plays an important role in carrying the capacity and stiffness of composite. As compared to other textiles, carbon textile better supported capacities, high tensile strength, high Young's modulus, low weight, high chemical resistance, etc. It is the main reason for the manufacture of Carbon textile as a commercial product for application in TRC composite. This study is extended to the production of carbon textile reinforced geopolymer composite based on the fine-grain geopolymer mortar matrix containing various contents of chopped basalt fibers. The workflow is carried out by evaluating the four-point flexural strength of geopolymer thin plates at a time period of 28 days after casting.

2 EXPERIMENTAL

2.1 *Materials*

Baucis LNa alumino-silicate geopolymer binder based on metakaolin was purchased from Ceske Lupkove Zavody, a.s. Czech Republic (in weight percent: SiO_2 - 47.4; Al_2O_3 - 29.7; CaO - 14.5; MgO - 2.6; TiO_2 - 1.8; Fe_2O_3 - 0.5; K_2O - 0.3; Na_2O - 1) along sodium silicate activator of modul 1.73 (in weight percent: SiO_2 - 20.72; Na_2O - 12.33; H_2O – 66.68). The metakaolin geopolymer was synthesized from calcined kaolin and shale clay residues with Si/Al ratio of 2.0. The kaolin was mainly composed of kaolinite with small amounts of quartz, whereas shale clay was composed of kaolinite with low amount of quartz and anatase. Two different types of silica sand were used as the fine aggregates for geopolymer mortar matrix (grain size: 0-0.063 mm and 0.6-1.25 mm). The chopped Basalt fibers were provided by Kamenny Vek, and the tows were 6.4 mm long with the individual fiber diameters of 13 μm, the density of 2.67 g/cm^3. Basalt has a softening and melting point of 1060°C, 1250°C, respectively. It is non-combustible, making it useful for high-temperature applications. The silane coating or sizing helps to protect the brittle fibers from premature fracture and prevents them from binding to each other. In this work, 3%, 5%, and 7.5% of chopped Basalt fiber additions (all by weight of geopolymer resin) were considered.

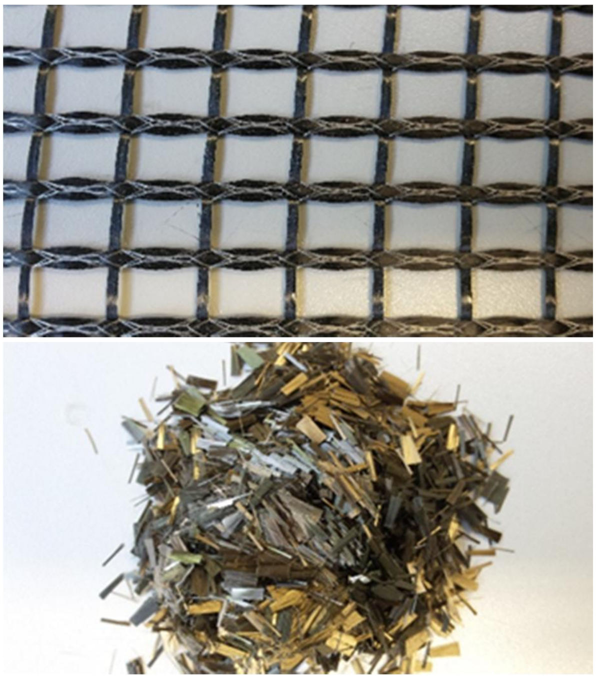
Carbon meshes of open size 12x16 mm were provided by Frisiverto s.r.o Company, Czechia. The carbon mesh was made up of 48000 individual filaments for the yarns in the longitudinal direction and 12000 individual filaments for yarns in the transverse direction, and density of 1.8 g/cm^3 (details see in Table 1). In the four-point bending test of geopolymer composite specimens, carbon grids were placed such that the load applied on the specimen was in the longitudinal direction of yarn.

Table 1 Properties of Carbon textile

Form	Carbon fiber grid
Fiber type **Binder yarn**	Carbon fiber HTC 10/15-40 PP 11 0dtex
Fiber construction **Tex**	Fiber orientation 0/90^o (bi-directional) 800 g/km
Fiber density	1.8 g/cm^3
Number of threads/m	78 (lengthways) and 55 (crossways)
weight	350 g/m^2
Coating	Styro Butadien
Stitch spacing	10 mm x 15 mm (center to center distance)
Tensile strength **Elongation lengthways** **Elongation crossways**	2551 N/mm^2 (lengthways) and 2847 N/mm^2 (crossways) 1.17% 1.24%

2.2 Specimen preparation and testing method

Geopolymer mortar matrix was prepared as the following steps. Pure geopolymer resin is the two-component mixture including aluminosilicate source (metakaolin) and alkaline liquid (sodium silicate liquid). This mixture is prepared in a ratio of solid to alkaline liquid (1:0.8) and mixed by mechanically stirring for approximately 5 min to ensure fresh mixture homogenously. After that micro-silica sand added into the prepared mixture and stirring for around 3 min more.



a)

b)

Figure 1 Textile reinforcement: (a) Carbon grid, (b) chopped Basalt fiber

Finally, chopped Basalt fiber (with the various percentage contents for each mixture) together with rough sand was added into the prepared mixture followed by stirring for another several minutes to ensure a homogenous mixture. The fresh mortar was cast into 30x30x150 mm^3 prismatic molds for the flexural and compressive test to evaluate the mechanical strength of geopolymer matrix. Three samples for each mixture were used for flexural test and then the compressive strength was measured on the far edge of both residual pieces obtained from flexural strength according to EN 196-1 standard [14]. The thin-plate molds with a dimension of 400x100x15 mm^3 for four-point bending were prepared. First the fresh mortar was poured in to the molds with a thickness 6 mm. Then one layer of textile is carefully laid over geopolymer mortar followed by filling the rest of the molds. Three thin plate specimens for each mixture were casted. All samples were cured at room temperature until test at a time period of 28 days after casting.

Figure 2 shows four-point bending test with constant bending moment zone (support span 100 mm) was used to determine the bending strength of geopolymer thin plate specimens. The INSTRON testing machine located at Technical University of Liberec Laboratory with the applied load under displacement control at loading rate of 2 mm/min. Three samples from each of the examined were tested.

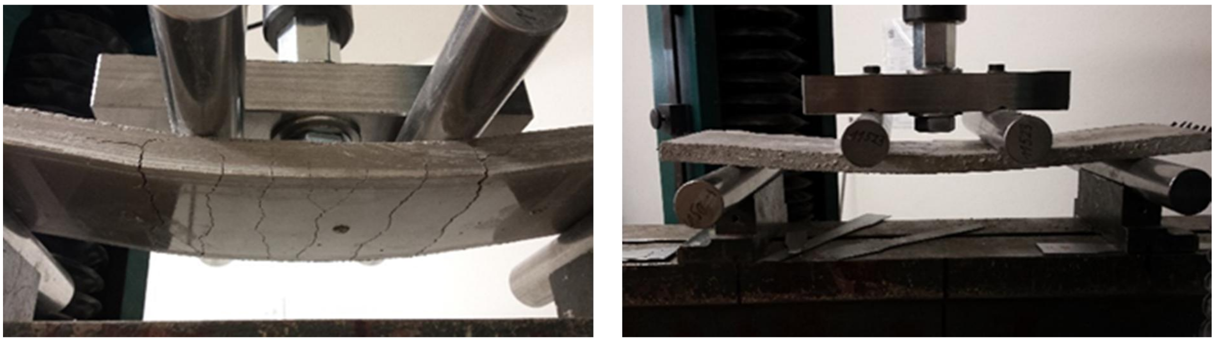


Figure 2 Four-point bending test of geopolymer composite thin plate

The calculation of the measured data and the evaluation of the test results were made using the following equation (1):

$$\sigma = F.l/(b.h^2) \quad [MPa] \qquad (1)$$

where σ is the four-point flexural strength in MPa; F is load at a given point on the load-deflection curve in N; b is the width of the tested sample in mm; h is the thickness of tested sample in mm; l is the support span (300 mm).

3 RESULTS AND DISCUSSION

Table 2 shows the compressive and flexural strength results of geopolymer mortar matrix at a maturation period of 28 days. In general, it can be seen that the addition of chopped Basalt fibers and their increasing percentage improved both of the compressive and flexural strength of geopolymer mortars. The strength of reference mortar is 11.04 MPa (flexural strength), and 64.36 MPa (compressive strength). After that addition of fiber increases the mechanical strength in gradually small value, it reaches a maximum value of 12.52 MPa (flexural strength), and 78.5 MPa (compressive strength) for fiber content of 7.5%.

Figure 3 shows the average flexural load-deflection curves of all the geopolymer thin plates containing various contents of chopped basalt fiber. In general, the flexural load-deflection curves of all the tested specimens exposed the similar behavior. It consists of the three parts corresponding to the stages in the flexural test. The three behavior areas are clearly visible. The first stage represents the linear uncrack state where the geopolymer matrix takes the load. Then, as the load increases, the stress transfers from the geopolymer matrix to the textile, which is represented by the multi-crack processing of the matrix. At the point or stage where the first crack takes the place is called transition point.

Then, the specimens continue to undergo a multi-cracking process, in which all of the stresses are transferred from matrix to the textile. At this stage, the textile is only carrying the load until it fails by rupturing or slipping. This behavior is similar to textile reinforced cementitious matrix [8].

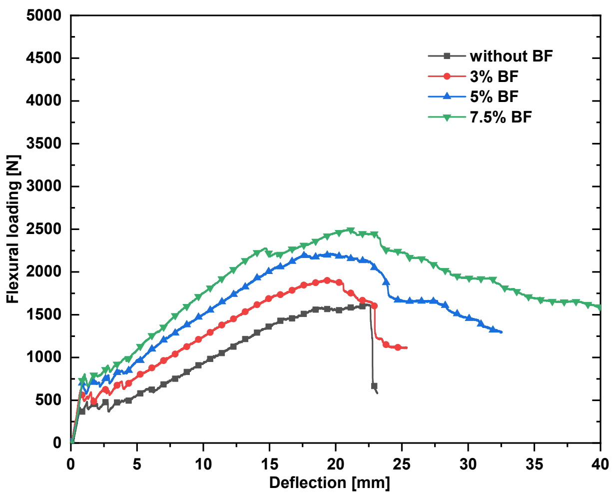


Figure 3 Flexural loading and deflection curves of one textile layer reinforced geopolymer composite thin plates with respect to various contents of BF

Figure 4 is presented average values of the first-crack stress, ultimate stresses and flexural toughness of thin plate specimens. It can be seen that the addition of BF reinforced geopolymer mortar is helpful to improve both the first-crack load and the ultimate load of textile reinforced geopolymer specimens. It can be observed by fact that BF contributes to improve the early age performance of the geopolymer mortar, leading to fewer micro-cracks in geopolymer mortar.

Table 2 Results of mechanical strength of geopolymer mortar matrix at time period of 28 days after casting

Mode	Various contents of chopped basalt fiber [wt.%]			
	0	3	5	7.5
Flexural strength [MPa]	11.23(0.39)	11.95(0.41)	12.77(0.19)	13.05(0.43)
Compressive strength [MPa]	64.36(3.17)	70.05(4.42)	78.52(1.67)	80.50(1.10)

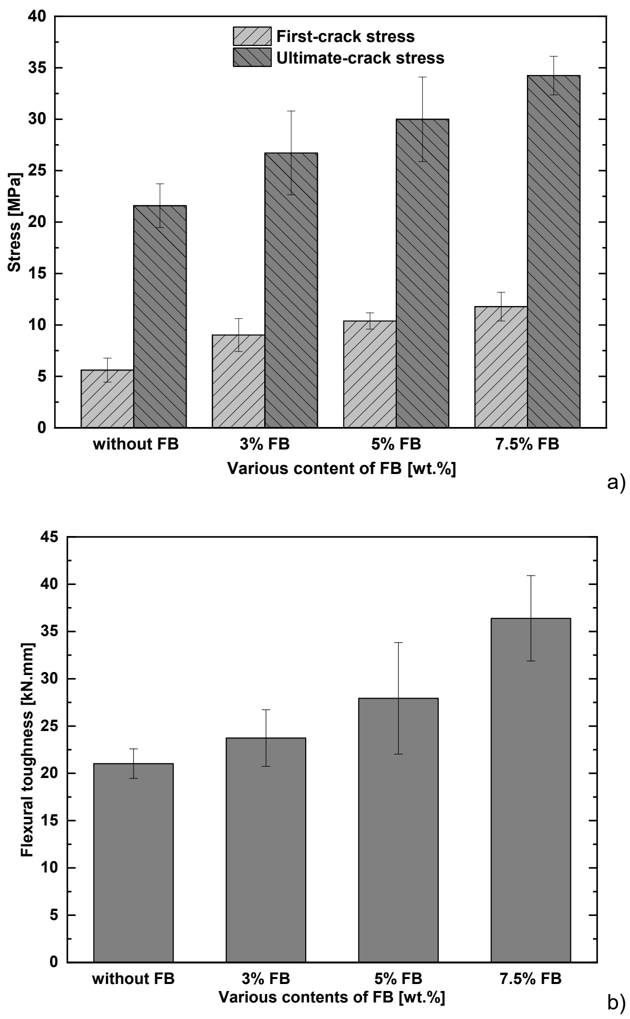


Figure 4 Summary of tested results of one textile layer reinforced geopolymer containing the various content of chopped basalt fiber: a) flexural strength; b) flexural toughness

Moreover, thanks to the bridge effect of basalt fiber at the cracks, the interface bond between yarns of textile and geopolymer matrix is improved, and thus it contributes to improving the efficiency of textile in reinforcing as well. BF reinforced geopolymer composites showed beneficial improvement in terms of flexural strength and the growing fiber content yielded the higher flexural strength when compared to geopolymer composites without addition BF.

The bearing capacity of textile reinforced specimens improved gradually with increasing content of BF. The average ultimate strength of specimens without addition BF is 21.59 MPa. The average ultimate strength of specimens with 3%, 5%, and 7.5% of addition BF increased by approximately 23.76%, 38.90%, and 58.59%, respectively, compared to specimens without addition BF (see in Figure 4a). Moreover, the flexural toughness of the specimens increases with increasing content of BF (see in Figure 4b). The average flexural toughness of specimens without BF addition is 21.03 kN.mm. The average flexural toughness of specimens with 3%, 5%, and 7.5% of addition BF increased by 12.89%, 32.81%, and 73.04%, respectively, compared to specimens without addition BF. Toughness is the ability of a material, which indicates how much energy it can absorb before rupturing. Toughness (energy absorption) is calculated as the area under the respective load-deflection curves up to peak load of each specimen.

Figure 5 displayed the failure modes of several thin plate specimens, which represented for the common failure modes of all the thin plate specimens after finishing bending test. Figure 5a showed the failure mode of specimens reinforced with one textile layer and without addition of BF. When these specimens failed, the bottom of specimens was broken and debonding along the matrix-textile interface did occur. As the applied load continue to increase, the interfacial debonding increased followed by collapse of geopolymer matrix. On the contrary, specimens with addition of 7.5% BF, matrix-textile interfacial debonding did not occur, as seen clearly in Figure 5b. Failure mode of these specimens resulted in flexural failure by slipping of textile yarn in geopolymer matrix.

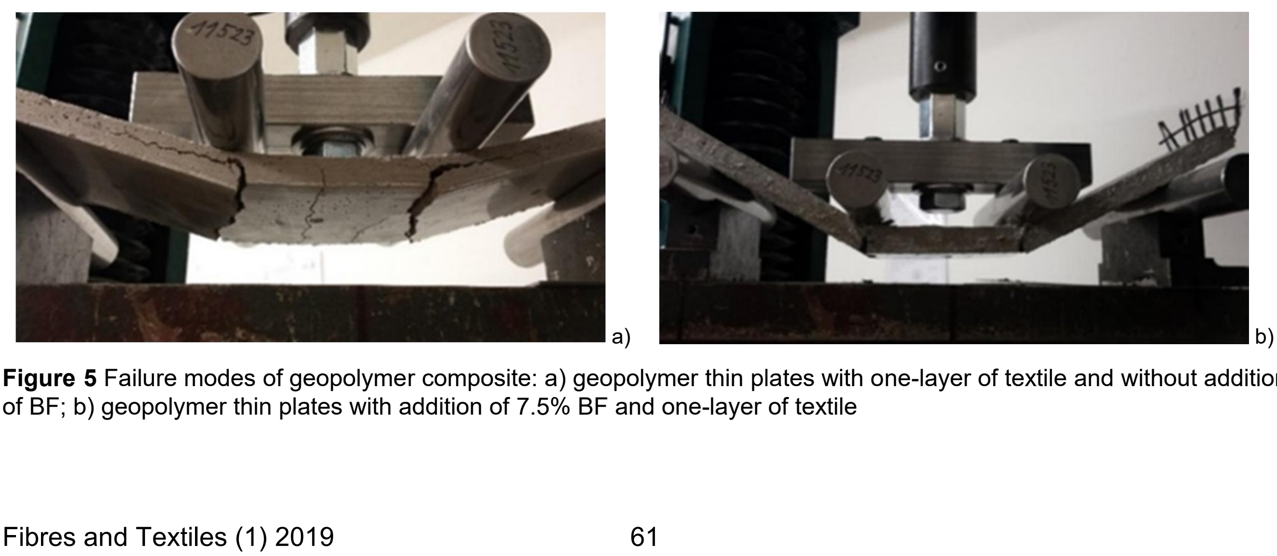


Figure 5 Failure modes of geopolymer composite: a) geopolymer thin plates with one-layer of textile and without addition of BF; b) geopolymer thin plates with addition of 7.5% BF and one-layer of textile

4 CONCLUSIONS

The flexural behavior of one-layer textile reinforced geopolymer thin plates containing various contents of BF was investigated and tested. The attained results from experiment show that the addition of BF reinforced geopolymer mortar is helpful to improve both the first-crack load, the ultimate load, and flexural toughness of textile reinforced geopolymer specimens. By visual observation of the specimens during the bending test, they indicated the different failure behaviors. The specimens without BF or with low content of BF exhibited the similar failure by debonding along the matrix-textile interface, whereas the specimens with high content of BF resulted in bending failure by slipping of textile yarn in matrix.

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