Mechanical properties of geopolymers reinforced with carbon and aramid long fibers

M Łach¹, M Hebdowska-Krupa¹, Dariusz Mierzwiński¹ and Kinga Korniejenko¹

¹Institute of Materials Engineering, Faculty of Materials Engineering and Physics, Cracow University of Technology, Jana Pawła II 37, 31-864 Cracow, Poland.

E-mail: michal.lach@pk.edu.pl

Abstract. The paper presents the results of the study of geopolymer composites reinforced with carbon and aramid fibers. Geopolymers were made on the basis of fly ash activated with 10 mole sodium hydroxide solution with an addition of aqueous sodium silicate solution. The fibers were introduced in the form of a roving. Carbon fibers 800 tex and aramid fibers 805 tex were used. Additionally, to compare the influence of the number of fibers on the properties of geopolymer composites for carbon fiber, 1600 tex fiber was also used. The flexural strength of composites made with the fibers was tested. Fiber reinforced geopolymer composites showed a higher value of flexural strength than unreinforced ones. The higher value was noted for carbon fiber reinforced composites (800 tex) compared to aramid fiber roving composites (805 tex). The study also showed that the application of higher fiber mass in the case of carbon fiber roving does not bring the expected increase in mechanical properties of the composites. The use of carbon fiber roving (1600 tex) resulted in a lower flexural strength than in the case of 800 tex roving. Double increase of fiber mass in the composite caused a decrease in strength parameters.

1. Introduction

The subject of geopolymer composites reinforcement has been developing dynamically in recent years, offering interesting research and application perspectives. The addition of fibers is mainly aimed at improving mechanical properties, in particular flexural strength [1, 2], and additionally it reduces the propagation of micro-cracks in the material and increases the resistance to brittle fracture [3]. The fibers can also increase the amount of energy absorbed by the geopolymer before the occurrence of damage [4]. An addition of fibers changes the character of the breakthrough from brittle to more ductile. It also reduces the number of cracks and their dimensions—the width of cracks is limited. General brittle behavior is suppressed in favor of an increased ductility [5]. This makes it possible to maintain material consistency for a longer period of time, which can be crucial, especially in emergency situations, in order to save people inside the structure in the event of a construction disaster. Introducing fibers into the geopolymer matrix creates an extremely interesting material for structural solutions, which stands out from other solutions currently available on the construction market.

Modern reinforcements used in geopolymer composites are usually based on inorganic fibers, such as carbon or glass fibers [6, 7] or synthetic fibers [8]. However, the direction of research is clearly...
visible, undertaking work on natural fiber reinforcement [9, 10]. This solution is to be an environmentally friendly alternative. It is worth noting, however, that natural fiber reinforcements give lower mechanical properties, which does not always allow for their desired applications [11, 12]. Inorganic fibers usually have higher strength properties and higher repeatability than natural fibers, which allows to obtain a homogeneous material [2, 13].

The fiber content in such composites varies significantly, from only 0.1% by weight for short fibers to 20% for mats or felt [14, 15]. Experiments with a higher number of fibers were also conducted, but they do not improve the strength parameters of the composites [16]. Additionally, increasing fiber content may cause a decrease in mechanical strength [17]. It should also be noted that increasing the number of reinforcement layers is not always associated with the improvement of mechanical properties. Studies of flexural strength of geopolymers reinforced with three layers of textile material showed that the parameters of such a composite did not improve compared to those reinforced with two textile layers [18].

In the presented study, the choice of carbon and aramid fibers was made because of the expected improvement in mechanical properties. It is worth noting that while earlier research works on carbon fibers were conducted in a wide range, there are few publications in the case of aramid fibers as reinforcements of geopolymer composites.

An increasing use of carbon fibers is associated with their numerous advantages: low density, high tensile strength and high Young modulus, high fatigue strength and creep resistance, abrasion resistance, infusibility, high chemical resistance, high dimensional stability, good electrical conductivity, low friction coefficient, vibration damping ability and low absorption of X-rays [19]. The disadvantages of carbon fibers include the tendency to oxidation in the oxygen environment under the influence of high temperatures (in non-oxidative atmospheres, at temperatures up to 2000°C carbon fibers do not lose their properties). It should be noted, however, that carbon fiber oxidation is catalyzed by the alkaline environment [19]. This property makes the geopolymer matrix, having an alkaline reaction, a promising possibility for the production of composites, which can also operate at high temperatures.

Carbon fibers in geopolymer composites were most often used in the form of long fibers [20, 21], fabrics [22], carbon fiber felt [23, 24], as well as the addition of other carbon forms, i.e., graphene [25, 26] graphite [27] or carbon fiber waste used in the production of aviation products [28]. The last three additives were most frequently introduced to geopolymers in the form of particles. The main barrier in the application of these fibers on an industrial scale is their high price. However, it should be noted that in the coming years new carbon fiber production technologies are expected to enter the market and this would be related to the decline in their prices. Studies with the use of short carbon fibers were conducted, inter alia, with the use of a metakaoline matrix with the addition of slag from the Italian company Acciaieria di RubieraSpA, in Casalgrande [29]. The flexural strength of composites with 1.0% weight content of 10 µm diameter and 7 mm length fibers was studied. The work carried out showed the reinforcement of the material. For a pure matrix, the flexural strength was 6.9 MPa and for composites with reinforcement it was 11.7 MPa [29].

Research works on carbon fiber reinforced geopolymer composites were also conducted on a geopolymer matrix based on fly ash from the Mae Moh power plant in Lampang, Thailand [30]. Cut carbon fibers in the following weight proportions were added to the composites: 0.0, 0.1, 0.2, 0.3, 0.4 and 0.5%. Two types of specimens were examined-seasoned at 25°C and 60°C. The study was carried out after 7, 14 and 28 days, gradually observing an increase in compression strength of the composites [30]. After 28 days, the best results were obtained for 0.5% of carbon fiber content. For the samples matured at 25°C it was about 43 MPa for the composite with 0.5% fiber added, compared to matrix material that obtained 30 MPa. For the samples matured at 60°C it was about 58 MPa for the composite with 0.5% fiber added. The matrix material produced under the same conditions obtained 45 MPa [30]. Apart from the studies of compressive strength, the research related to electrical conductivity of the composites were also carried out. An increase in conductivity along with an increase in the number of carbon fibers was noted [30].
In the range of ambient temperatures, the main purpose of carbon fibers addition was to increase mechanical properties and change the behavior of composites in the range of fracture characteristics-to avoid brittle breakthrough [6]. However, it is worth noting that these are not the only advantages associated with the use of this fiber-a large part of the research was devoted to the possibility of application of geopolymer composites reinforced with carbon fibers as a material for applications at elevated temperatures. The studies of behavior of geopolymer composites with addition of short carbon fibers at high temperatures were conducted on a geopolymer matrix based on fly ash from the Gladstone power plant in Queensland, Australia [31]. The fibers were added in amounts of 0, 0.5, 1 and 1.5% by weight. The study was carried out at temperatures: 28°C, 200°C, 400°C, 600°C and 800°C. The fibers had the following dimensions: diameter about 11 μm and length 6 mm [31]. The results of examination of compression strength at ambient temperature show an increase in its value for composites containing 1 and 1.5% of carbon fiber (about 31 and 32 MPa, respectively) and a decrease in its value for material containing 0.5% of fiber - about 27 MPa, in relation to material without additives-about 29 MPa [31]. At temperatures of 200°C, 400°C and 600°C, the properties of composites increase compared to the corresponding materials tested at ambient temperature-28°C. The properties of some composites decrease only at the temperature of 800°C, while for the specimens with 0 and 1.5% contents the compression strength increases slightly, while for the composites with 0.5 and 1.5% contents it decreases. The highest value in the study was achieved by fiber composites at 200°C, i.e., 0.5%-about 36 MPa, 1%-about 40 MPa and 1.5%-about 36 MPa, respectively. The specimen without the addition of fibers obtained the highest value of compression strength at the temperature of about 37 MPa [31]. The study confirms the possibility of using the composites with the addition of carbon fiber in applications for high temperatures.

Studies on carbon fiber addition, including the influence of temperature on the mechanical properties of composites, were also conducted on a matrix based on a mixture of metakaoline with fly ash. Fly ash came from the Guangzhou Huangpu power plant in China [32]. Carbon fibers of the following dimensions were added to the composites: length: 6 mm, diameter: 7 μm. The following addition of fibers by weight was applied: 0, 0.5, 1 and 2%. The specimens were examined after 7 days at ambient temperature and 500°C [193]. The results of compressive strength at ambient temperature showed a decrease in its value from about 50 MPa for a material without fiber addition to about 45 MPa for a material with 2% addition of carbon fibers. However, at 500°C the material with fibers addition was more resistant and reached about 5 MPa for fiber composites, compared to about 2 MPa for material without fibers [32]. The flexural strength increased with the addition of fibers both at ambient temperature and at 500°C. For the material without fiber addition it was about 5.5 MPa and below 0.1 MPa, while for the composites with 2% addition of carbon fibers it was 15 MPa and 1 MPa [32]. The study showed that the mechanical properties of fiber composites significantly decrease above 200°C [32].

The studies were also conducted on the addition of micro and nano carbon fibers (in the form of nanotubes) to geopolymer composites. The study on the addition of microfibers (fibers of the length of about 100 μm) were carried out in the ratio of 0, 5, 10 and 15% by weight to a geopolymer matrix based on metakaoline [33]. The examinations were carried out after 28 days at temperatures of 30°C, 200°C, 400°C and 800°C. The highest values for temperatures 30°C and 200°C were obtained for 10% microfiber addition, while the values for 200°C were higher than for temperature of 30°C. The values for 30°C were 44.2 MPa for the material with 10% microfibers and 28.4 MPa for the matrix material, while for the temperature 200°C it was 48.8 MPa for the material with microfibers and 36.6 MPa for the matrix material. The highest values for temperatures of 400°C and 800°C were obtained for 15% fiber addition: 33.5 MPa and 24 MPa, respectively, for the same temperatures the compressive strength of the material without fiber addition was: 14.8 MPa and 11.2 MPa [33]. The studies were also carried out on the addition of carbon nanotubes to geopolymers both as an additive to matrices based on metakaoline [34, 35] and fly ash [36]. The addition of nanotubes increased the mechanical properties of composites.
Few studies were carried out with the use of aramid fiber as a reinforcement of geopolymer composites, however, they show a positive influence on the mechanical properties of the composites. The study was carried out with the use of a geopolymer matrix based on fly ash. After the specimens were prepared, they were subjected to high temperature, 85°C for 10 hours [37]. Aramid fibers of 30 mm length and 0.5 mm diameter in 1.0% volumetric ratio were used as an addition [37]. In this case, the matrix material reached the value of compression strength of 70 MPa, while the composites with added fibers-88.0 MPa [37]. Significant increase of the value was observed for flexural strength and it was 10.4 MPa for composite with 1.0% fiber content, compared to 7.1 MPa obtained for pure matrix material and tensile strength increase from 3.1 MPa for matrix material to 7.7 MPa for composite material [37].

The paper presents the results of the study on geopolymeric composites reinforced with carbon and aramid fibers. The fibers were introduced in the form of roving. Carbon fibers 800 tex and aramid fibers 805 tex were used. Additionally, in order to compare the influence of the number of fibers on the properties of geopolymer composites for carbon fiber, the 1600 tex fiber was also used.

2. Material and methods

2.1. Material
Geopolymers were made from fly ash from the CHP plant in Skawina (Poland) and sand in ratio 1:1. The fly ash came from the coal power plant ‘Skawina’ (located in: Skawina, Lesser Poland, Poland) was used. This fly ash is obtained from a bituminous coal by electrostatic precipitation of fine particles from the exhaust gases from coal-fired furnaces. The chemical composition of the fly ash is typical for class F according to ASTM678 standards (ASTM-C618-2). It is rich in oxides such as SiO$_2$ (55.89%) and Al$_2$O$_3$ (23.49%) and contains low amount of CaO (2.72%). It has also good physical parameters - the content of particle under the size 45 μm is about 88%. The morphology of the particles of this fly ash is typical of such by-products of coal combustion and suitable for the process of alkali-activation [15]. The silica sand has been use as an aggregate.

Two types of fibers in the form of roving were used: 800 tex carbon and 1600 tex and 805 tex aramid fibers. Selected parameters of the fibers used are given in Table 1.

| Type of roving | Nominal linear mass of roving, tex | Width | Producer              |
|---------------|-----------------------------------|-------|----------------------|
| Carbon        | 800                               | 5 mm  | Havel Composites     |
| Carbon        | 1600                              | 10 mm | Havel Composites     |
| Aramid        | 805                               | 8 mm  | Havel Composites     |

The fibers are used in the condition as received from the manufacturer. They were not subject to prior processing.

2.2. Samples preparation
Four series of composites were prepared: with carbon fibres (tex 800) and (tex 1600), aramid fibres (tex 805) and one control series without any fibres. The matrix was prepared using sodium promoter, fly ash, sand. The process of activation has been made by 10M sodium hydroxide solution combined with the sodium silicate solution (the ratio of liquid glass - 1:2) and the tap water. The solution was mixed and left until its temperature became stable and the concentrations equalized, which took, about 2 hours. The fly ash, sand and alkaline solution were mixed about 10 minutes by using low speed mixing machine (to receive the homogeneous paste).

Geopolymer composites were made in molds with dimensions of 20×50×200 mm. Three types of compositions were made in which 1 linear meter of roving, evenly distributed in one layer, and control
specimens without reinforcement were used. Figure 1 shows the distribution of fibers in the specimens.

Figure 1. The method of roving arrangement in the specimens prepared for the study-top-down projection.

Next, tightly closed molds were heated in the laboratory dryer for 24h at 75 °C. Then, the samples were unmolded. Each series of samples were tested on flexural strength at ambient temperature after 28 days.

2.3. Research methods
Flexural strength tests were carried out according to the methodology described in the standard EN 12390-5 (‘Testing hardened concrete. Flexural strength of test specimens’), because of the lack of separate standards for geopolymer materials. The tests for each series involved 5 prismatic samples: 50 x 50 x 200 mm (space between supporting points 150 mm). Tests were performed on an universal testing machine - MATEST 3000kN with speed 0,05 MPa/s. The calculations were based on following equation:

\[ f_{cf} = \frac{3F \cdot l}{2 \cdot d_1 \cdot d_2^2} \]  

where:
- \( f_{cf} \) – compressive strength, MPa
- \( F \) – maximal load, N
- \( l \) – space between supporting points, mm (for conducted tests: 140 mm)
- \( d_1, d_2 \) – sample dimensions, mm

3. Results and discussion
The results from the flexural strength tests are shown in table 2. The results of both methods and samples with fiber reinforced and control specimens (without fibers) are presented.

| Series | Type of fiber            | Flexural strength [MPa] | Average value[MPa] | Standard deviation |
|--------|--------------------------|-------------------------|--------------------|--------------------|
| 1      | no reinforcement         | 7,141                   | 7,2                | 0,21               |
|        |                          | 6,920                   |                    |                    |
|        |                          | 7,218                   |                    |                    |
|        |                          | 7,440                   |                    |                    |
| 2      | Carbon fiber 1mfiber 1600tex | 7,930                   | 6,6                | 0,81               |
|        |                          | 7,021                   |                    |                    |
|        |                          | 6,014                   |                    |                    |
|        |                          | 6,588                   |                    |                    |
| 3      | Carbon fiber 1mfiber 800tex | 7,861                   | 8,3                | 0,37               |
|        |                          | 8,435                   |                    |                    |
|        |                          | 8,672                   |                    |                    |
|        |                          | 8,043                   |                    |                    |
| 4      | Aramid fiber 1mfiber 805tex | 8,441                   | 7,7                | 0,67               |
|        |                          | 6,930                   |                    |                    |
|        |                          | 8,094                   |                    |                    |
|        |                          | 7,433                   |                    |                    |
In the case of geopolymer composites reinforced with fibers of about 800 tex, higher value of flexural strength compared to unreinforced geopolymer was noted. For carbon fiber (800 tex), it was an increase of about 15%, whereas for aramid fiber roving composites (805 tex) it was about 6% compared to the control specimens. The study also showed that the use of higher fiber mass in the case of carbon fiber roving does not bring the expected increase in flexural strength. The use of carbon fiber roving (1600 tex) resulted in a lower flexural strength than in the case of 800 tex roving and a lower flexural strength by about 8% compared to unreinforced material. This may indicate a lack of consistency between the thicker fiber and the matrix. However, this subject requires additional research.

![Figure 2. Specimens containing reinforcement in the form of carbon roving 1600 tex.](image)

In relation to the previously analyzed literature studies, it is worth noting that the results obtained with the use of the proposed reinforcement were lower than expected. The previous analysis showed that as a result of carbon fiber reinforcement, the flexural strength improved by approx. 25–55% [29, 33], while in the case of aramid fiber application by 46% [37]. This indicates the need for further work on the reinforcement, or possibly the need to re-engineer its system and/or change the form of the reinforcement, e.g. to short or mixed fibers. It is also worth noting that a significant limitation in this respect is the planned use of composites for the production of incremental technology, which makes it impossible to use reinforcement in the form of mat or fabric.

It should also be noted that neither carbon nor aramid fibers have yet been investigated in additive manufacturing applications, i.e., 3D printing of geopolymers. So far, the only research activities in this respect have not been carried out in the area of steel and glass fibers. These fibers were examined both as continuous reinforcement-steel fibers [38] and dispersed reinforcement-glass fibers [39]. The dispersed reinforcement was added to geopolymer filaments based on fly ash, slag, silica and sand as 3 mm, 6 mm and 8 mm fibers in amounts ranging from 0.25% to 1%. The 1% addition of reinforcement significantly improved the properties of printed materials, especially flexural strength, which facilitated the entire 3D printing process [39].

4. Conclusions
Carbon and aramid fibers in the form of roving were used in the study. The matrix of the composite was a geopolymer made on the basis of fly ash and building sand, activated with 10 M NaOH with the addition of an aqueous solution of sodium silicate in a ratio of 1:2 wt. %. Fiber reinforced geopolymer composites showed a higher value of flexural strength compared to unreinforced geopolymer. The higher value was observed for carbon fiber reinforced composites (800 tex) compared to aramid fiber roving composites (805 tex). The study also showed that the use of higher fiber mass in carbon fiber roving does not bring the expected increase in flexural strength. The use of carbon fiber roving (1600 tex) resulted in a lower flexural strength than 800 tex roving. Double increase in fiber mass in the composite caused a decrease in strength parameters.
The conducted study is an initial research aimed at selecting the most beneficial form of geopolymer composites reinforcement, which are planned to be carried out with the use of additive technology. It is planned to continue research in this area, in particular to determine the influence of fibers on the rheological properties of the composite and to test the influence of fiber addition in terms of providing the composite with other properties, i.e., resistance to temperature or corrosive environments.

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References
[1] Silva FJ and Thaumaturgo C 2003 Fatigue & Fracture of Eng. Mat. & Structures 26 (2) 167
[2] Mikula J and Korniejenko K 2015 Innovative, Cost-Effective and Eco-friendly Fibre-based Materials for the Construction Industry (Kraków: Wydawnictwo Politechniki Krakowskiej)
[3] Rickard WDA, Vickers L and van Riessen A 2013 Appl. Clay Sci. 73 71
[4] Chen R, Ahmari S and Zhang L 2014 J. Mat. Sci. 49 2548
[5] Sakulich AR 2011 Sustain. Cities Soc. 1 195
[6] Lin T, Jia C, He P and Wang M, 2010 Mat. Sci. Eng. A-Struct. 527 2404
[7] Lin T, Jia D, Wang M, He P and Liang D 2009 B. Mater. Sci. 32 (1) 77
[8] Yan L, Kasal B and Huang L 2016 Compos. Part B-Eng 92 94
[9] Rashad A M 2018 Natural Resources Conservation & Research” 19
[10] Sa Ribeiro R A, Sa Ribeiro M G and Kriven W M 2017 J. Ceramics Sci. & Technology y 8 (3) 307
[11] Korniejenko K, Frączek E, Pytlak E and Adamski 2016 Procedia Engineer. 151 388
[12] Szeczyńska-Hebda M, Marczyk J, Ziejewska C, Hordyńska N, Mikula J and Hebda M 2019 Materials 12 (18) 2999
[13] Trindade A, Borges P and Silva F 2019 Advances in Civil Eng. Materials 8 (article in press)
[14] Davidovits J 2016 Reinforced Geopolymer Composites: A critical review, published on line: https://www.materialstoday.com/polymers-soft-materials/features/reinforced-geopolymer-composites-a-critical-review/ (access: 23-09-2019)
[15] Korniejenko K 2019 Wpływ dodatku włókien krótkich na właściwości mechaniczne kompozytów na osnowie geopolimerowej (Kraków: Biblioteka Cyfrowa Politechniki Krakowskiej)
[16] Furtos G, Silaghi-Dumitrescu L, Pascuta P, Sarosi C and Korniejenko K 2019 J. Nat. Fibers (article in press)
[17] Payakaniti P, Pinitsoonthorn S, Thongbai P, Amornkitbamrung V and Chindaprasirt P 2018 Materials Today: Proceedings 5 (6) 14017
[18] Chi H L, Louda P, Periyasamy A P, Bakalova T and Kovacic V 2018 Fibers 6 87
[19] Mayer P and Kaczmar J W 2008 Tworzywa Sztuczne i Chemia 6/2008 52
[20] Pernica D, Reis P N B, Ferreira J A M and Louda P 2010 J. Mater. Sci. 45 744
[21] Tran D H, Kroisová D, Louda P, Bortnovsky O and Bezucha P 2009 J. Achievements in Materials & Manufacturing Eng. 37 (2) 492

[22] Zhang H, Hao X and Fan W 2016 Procedia Engineer. 135 47

[23] Yan S, He P, Jia D, Yang Z, Duan X, Wang S and Zhou Y 2016 Ceram. Int. 42 7837

[24] He P, Jia L, Ma G, Wang R, Yuan J, Duan X, Yang Z and Jia D 2018 Ceram. Int. 44 10726

[25] Yan S, He P, Jia D, Yang Z, Duan X, Wang S and Zhou Y 2015 Ceram. Int. 41 (9) 11242

[26] Ranjbar N, Mehrali M, Mehrali M, Alengarama U J and Jumaat M Z 2015 Cement Concrete Res. 76 222

[27] Zhang Y, He P, Yuan J, Yang C, Jia D and Zhou Y 2017 Ceram. Int. 43 2325

[28] Luna-Galiano Y, Leiva C, Villegas R, Arroyo F, Vilches L and Fernández-Pereira C 2018 Mater. Lett. 233 1

[29] Natali A, Manzi S, Bignozzi MC 2011 Procedia Engineer. 21 1124

[30] Payakaniti P, Pinitsoontorn S, Thongbai P, Amornkitbamrung V and Chindaprasirt P 2017 Constr. Build. Mater. 135 164

[31] Shaikh F and Haque S 2018 Int. J. Concr. Struct. M. 12 (35) 12

[32] Zhang H, Kodur V, Cao L and Qi S 2014 Procedia Engineer. 71 153

[33] Behera P, Baheti V, Militky J and Naeem S 2018 Constr. Build. Mater. 160 733

[34] Abbasi S M, Ahmadi H, Khalaj G and Ghasemi B 2016 Ceram. Int. 42 15171

[35] Yuan J, He P, Jia D, Fu S, Zhang Y, Liu X, Cai D, Yang Z, Duan X, Wang S and Zhou Y 2017 J. Eur. Ceram. Soc. 37 2219

[36] Saafi M, Andrew K, Tang P L, McGhon D, Taylor S, Rahman M, Yang S and Zhou X 2013 Constr. Build. Mater. 49 46

[37] Zhu J, Zheng W Z, Qin C Z, Xu Z Z and Wu Y Q 2018 IOP Conf. Series: Materials Sci. & Eng. 292 012060

[38] Lim JH, Panda B and Pham Q-C 2018 Constr. Build. Mater. 178 32

[39] Panda B, Paul S C and Tan M J 2017 Mater. Lett. 209 146