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CHARACTERIZATION OF MECHANICAL PROPERTIES OF SHORT GLASS FIBER-REINFORCED GEOPOLYMER COMPOSITES

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Key words: Fly ash, geopolymer composites, glass fiber.

Summary: *Geopolymers have good compressive strength, durability and thermal (high flame and heat resistance). Weakness of such composites is primarily related to relatively low tensile and flexural strength, which limits their use in many areas. The paper describes the mechanical properties of fly-ash based geopolymer reinforced with short glass fibers (1-5%). The article aims is to analyze the influence of addition glass fibers on mechanical properties of geopolymers. The empirical part was based on the following tests: compressive strength and microstructure investigations. Results show that the appropriate addition of glass fibers can improve the mechanical properties of geopolymer composites.*

1 INTRODUCTION

An important factor in the growth of interest of geopolymers as a new material is also a growing public awareness of the need to protect the environment. Geopolymers can be synthesized by alkali activation of a lot of sources such as fly ash, slag, red muds, metakaolin, silica fume, volcanic ashes and even rice husk ash. The basic advantages of material made from fly ash is a wide availability of large volumes of fly ash in many parts of the world [1] and low price. During the production of geopolymers can be reused of fly ash utilizes materials that would otherwise be disposed of in landfills [2].

It is also important that geopolymers caused significant reduction in environmental footprint. This material not only can be made from fly ashes, but also during its production much lower amount of greenhouse gases is emitted in comparison to the traditional construction materials such as Portland cement [1, 3, 4]. It is estimated, that the use of Portland cement as the main component during the production of concrete is responsible for about 6% of the carbon dioxide emission [5-7]. The manufacturing of geopolymers is accompanied by the 4–8 times smaller release of carbon dioxide and by 2-3 times smaller energy consumption comparison to the cement production [4, 5, 9, 10]. The material can be manufactured under ambient (room temperature) as well as slightly elevated temperature [1].

In comparison to the traditional materials, such as concrete, alkali activated materials have a number of advantages. They have a comparable and even better properties, especially possess good mechanical properties, inflammability, acid resistance and durability [4, 8]. Additionlly, the long-term properties of fly-ash based geopolymers might be much improved over what was initially reported for early ages [2]. They can also operate innormal ambient conditions (being an environmental-friendly alternative), and in extreme conditions (in which traditional materials wear out quickly and cannot be used at all) [9, 11]. The production of such composites, compared to the materials for special applications (working in difficult conditions) has the low energy consumption and because of that is economically advantageous [3, 7].

Geopolymer weaknesses are relatively low tensile and flexural strength, like most ceramics, which limits their application in many areas [4, 7]. Concerning the structural applications, fiber-reinforced materials possesses many advantages compared to the traditional one [12]. Addition of fibers in brittle matrices is efficient method for the improvement of fracture toughness [13]. Fibers reduces effect of cracking. In a fiber-reinforced materials, the widths of cracks are limited (eg. reduction of the propagation of microcracks) and overall brittle behavior is suppressed in favour of enhanced ductility [2, 132]. Thanks to it damage caused by cracking would be mitigated - post cracking strength is a reason of using a fibers in materials such as concrete or geopolymers [2, 4, 14].

The most common fiber reinforcements used in geopolymer composites is based on inorganic fibers such as carbon or glass fibers [15 - 18]. The use of glass fibers is investigated, because they are cheaper than carbon fibers [2]. Introducing the short fibres as reinforcement of cementations compounds as well as geopolymers offers physical and mechanical advantages [17, 18]. Short fibres are effective reinforcements in strengthening and toughening geopolymer materials [15]. Compared to continuous (long) fibers reinforced composites, short fibers reinforced composites combine easier adaptability to conventional manufacturing techniques and low producing cost [16, 19]. The most important factors that affect the short fibres reinforcement are fibre dispersion (methods for obtaining homogeneous distribution within matrix) and fiber aspect ratio. Fiber damage, agglomeration of fibres and the generation of voids can influence on the quality of the composite [20, 21].

Nowadays, the fiber reinforced composite materials have been playing an important role in different branch of economy. The composites are used for repair of damaged structures (strength to weight ratio, corrosion resistance low shrinkage and ease of application) [22] as well as in high technologies such as aerospace, naval architecture, ground transportation or automotive industry [5, 23, 24].

2 MATERIAL AND METHODS

2.1 Material

Fly ashes collected from different power stations vary substantially in their chemistry and physical nature [1]. There are not always suitable for manufacturing geopolymers. It is depended on chemical composition and physical properties [2, 25].

The fly ash from power station located in Skawina (Poland) was investigated possibilities to use them to prepare geopolymeric matrix of composites. SEM observations and EDS analysis confirmed the possibility of using fly ash as a material to create a geopolymer matrix composites.

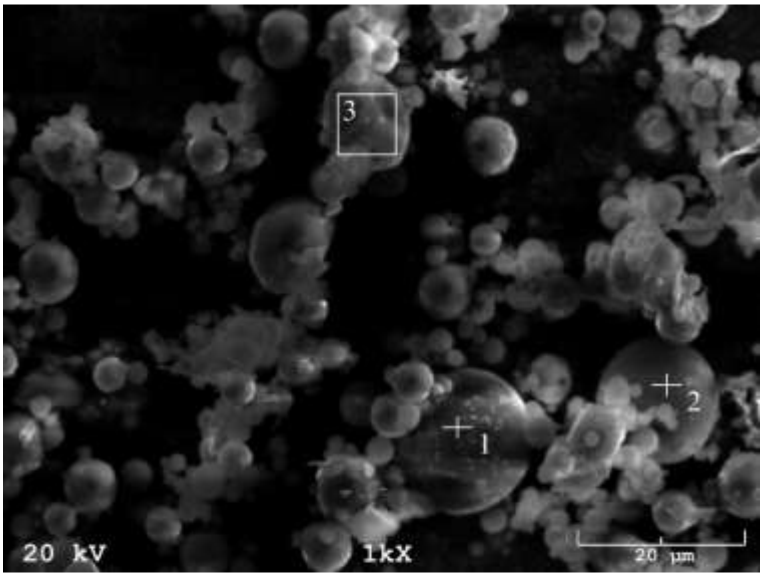

Figure 1: SEM image obtained from fly ash from power station located in Skawina (Poland).

Figure 1. shows the microstructure of the original fly ash before being activated with alkaline activator. The fly ash contains of spherical aluminosilicate particles of different sizes. The EDS analysis was made for chosen area (Figure 2.)

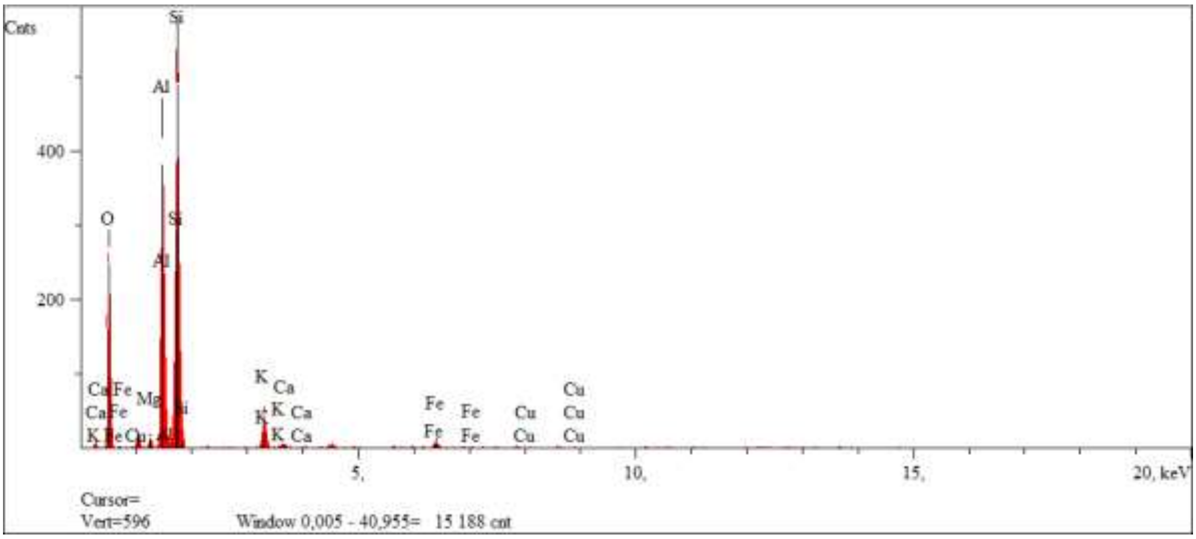

Figure 2: EDS analysis for area no. 3 from Figure 1.

Table 1. presents a chemical components for the original fly ash before being activated. The fly ash is rich in oxides such as SiO_2, Al_2O_3, Fe_2O_3. It is advantages for alkaline activation process.

No		**[%]**	**No**		**[%]**
1.	loss on ignition	2,84 ± 0,14	8.	Fe_2O_3	7,60
2.	SO_3	0,95 ± 0,24	9.	$SiO_2 + Al_2O_3 + Fe_2O_3$	78,21 ± 1,28
3.	chloride (Cl)	0,034 ± 0,010	10.	MgO	3,06 ± 0,23

4.	CaO	0,02 ± 0,01	11.	P_2O_5	0,0008 (8 ± 1 mg/kg)
5.	SiO_2 (reactive)	35,86 ± 0,64	12.	Na_2O	1,72
6.	SiO_2	47,81	13.	K_2O	4,62
7.	Al_2O_3	22,80	14.	Na_2O_{eq}	4,76 ± 0,47

Table 1: Composition of the fly ash from power station located in Skawina (Poland).

Additionally, the size of particles was investigated (Table 2.)

the size of particles [µm]	>160	100-160	71-100	63-71	56-63	<56
percentage	0.3	3.2	11.9	9.9	15.4	59.3

Table 2: Composition of the fly ash from power station located in Skawina (Poland).

For the addition were used standard glass fibres (Table 3.).

Tensile strength (MPa)	1300-3400
Modulus of elasticity (GPa)	22-62
Elongation (mm/mm)	0.03-0.5
Coefficient of thermal expansion (10^{-6m}/m/^oK)	5.5
Melting Point (^oC)	1100
Density (gr/cm^3)	2.5-2.6

Table 3: The basic material properties of E-glass [26].

Samples were prepared using sodium promoter and fibres addition for 1%, 2%, 15% and 5% by mass of the composite. An 8 M concentration of sodium hydroxide solution was prepared and combined with the sodium silicate solution. The fly ash, alkaline solution and fibres were mixed in a mechanical mixer to form a homogeneous paste. Next, there were heat at a temperature of 75^0C for a period of 24 hours. The samples were divided to two groups. One part was investigated after 7 days and the other one was sunk at the lake and there were tested after 28 days.

2.2 Measurements

The compressive strength test, due to the lack of standards for geopolymer materials was carried out according to the methodology described in the standard EN 12390 - Part 3:2001. Research - Concrete compressive strength. Samples used to the compressive strength test had cylindrical shape with dimensions: Ø = 36.5 mm h = 70 mm. Tests were performed on an universal testing machine - single-point load (Instron type 4465).

Microstructure research has been performed by scanning electron microscopy (SEM) type JEOL JSM 820 with EDS on samples previously broken while compressive strength test.

3 RESULTS

3.1 SEM observations

Microstructure research have enabled the analysis of complex structures geopolymers and determine their elemental composition. Research gives a preliminary information on the consistency of fiber (filler) and the geopolymer matrix (Figure 3-5).

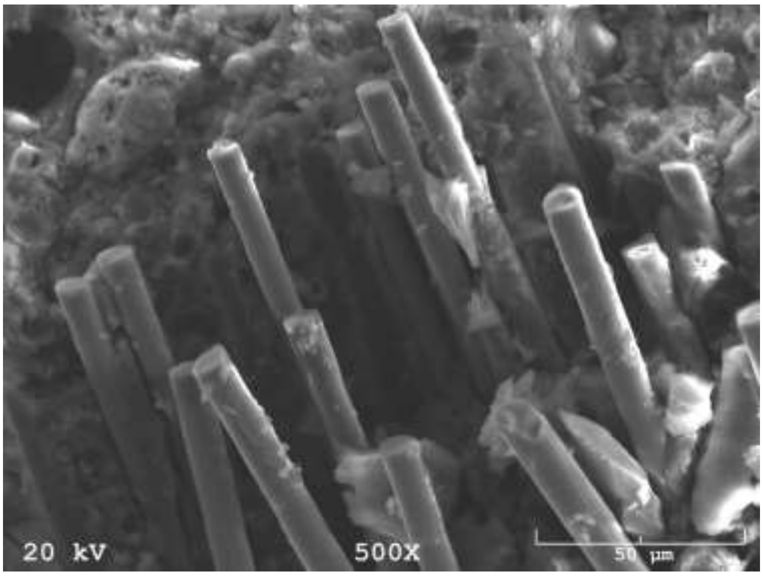

Figure 3: SEM image obtained with the addition of 1% glass fibers at a magnification of 500 x.

Figure 3. presents that some glass fiber are not distributed homogeneously within a matrix. The fiber distribution in the matrix plays crucial roles for the properties of the composites. The fibers aggregation caused low mechanical properties. The not regular structure was observed only a few samples.

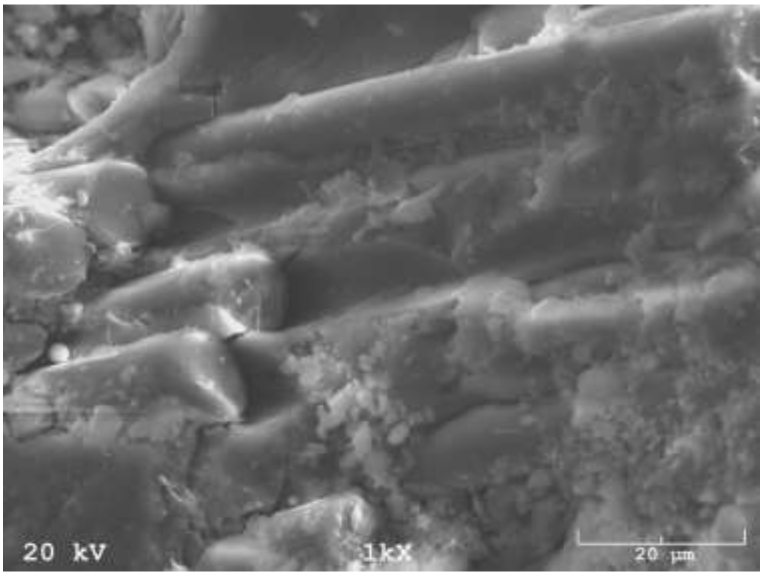

Figure 4: SEM image obtained with the addition of 5% glass fibers at a magnification of 1000 x.

Figure 4. shows coherency between fiber (filler) and the geopolymer matrix. It was also observed that fibers reduce a cracks propagation (SEM observation was made on samples after compressive test). This area was also analyzed on the higher magnification (Figure 5.) and some EDS analysis were made (Figure 6.).

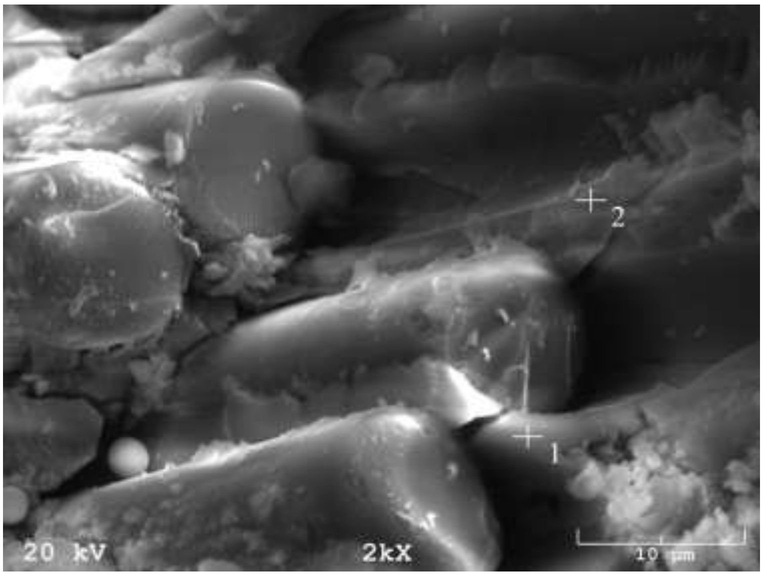

Figure 5: SEM image obtained with the addition of 5% glass fibers at a magnification of 2000 x.

The EDS analysis were confirmation for expected structure (Figure 6.).

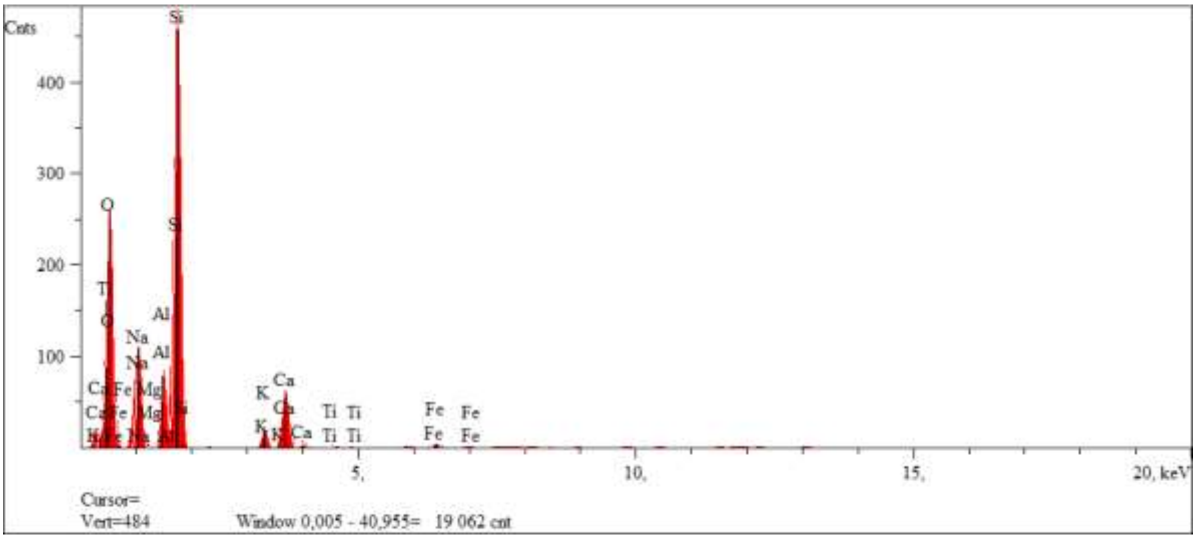

Figure 6: EDS analysis for point no. 1 from Figure 5.

The observation was made also for samples after 28 days with some efflorescence on the surface the samples (Figure 7.). The EDS analysis were made (Figure 8.) and also was investigated the occurrence of particular elements in the chosen area (Figure 9. and 10.).

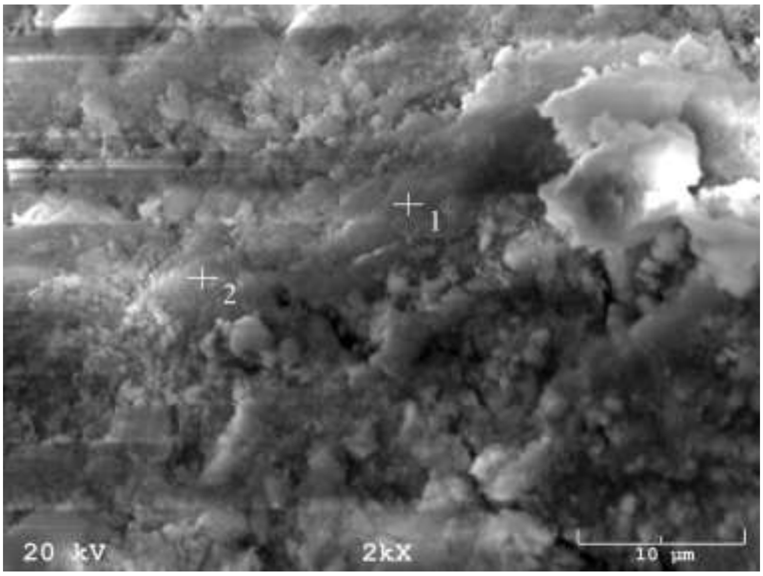

Figure 7: SEM image obtained with the addition of 2% glass fibers at a magnification of 2000 x.

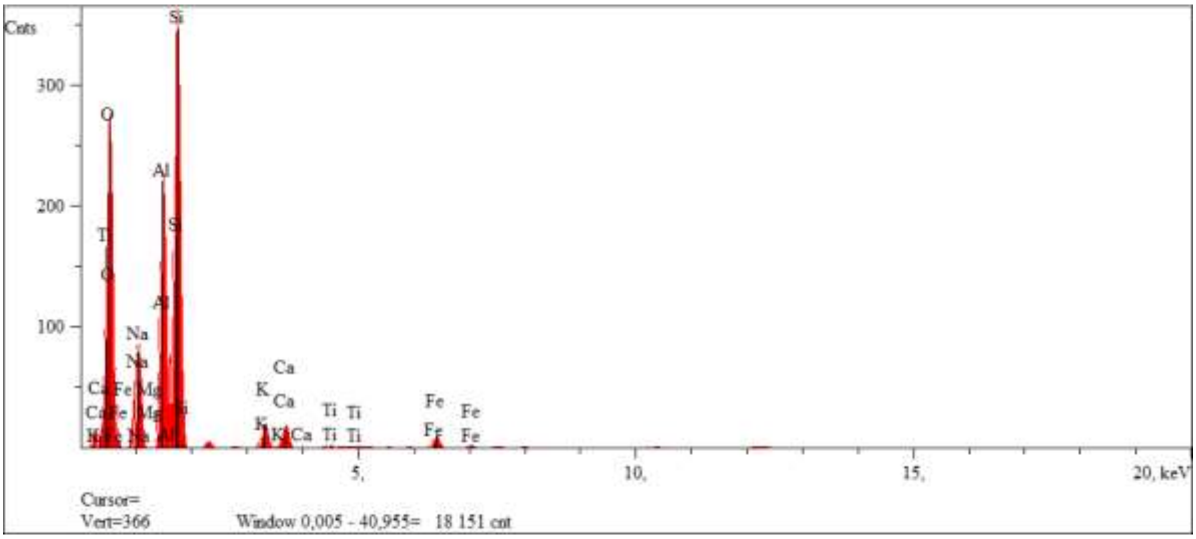

Figure 8: EDS analysis for point no. 1 from Figure 7.

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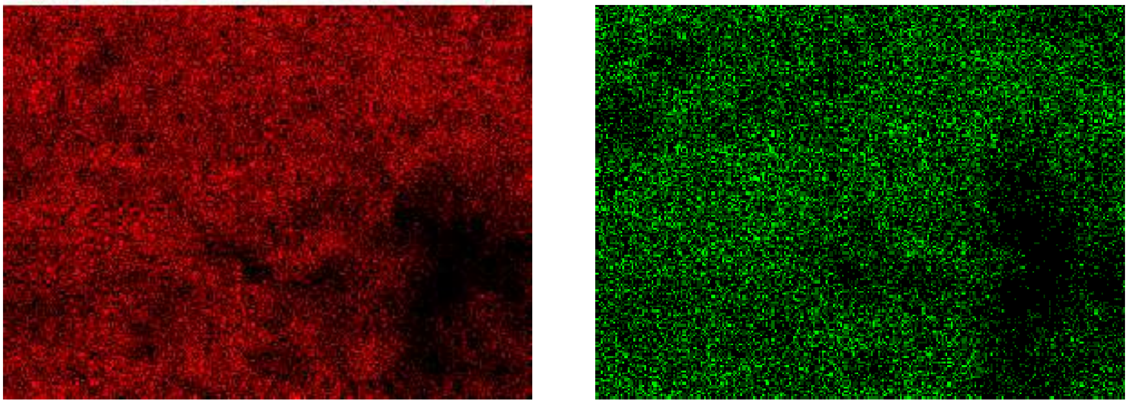

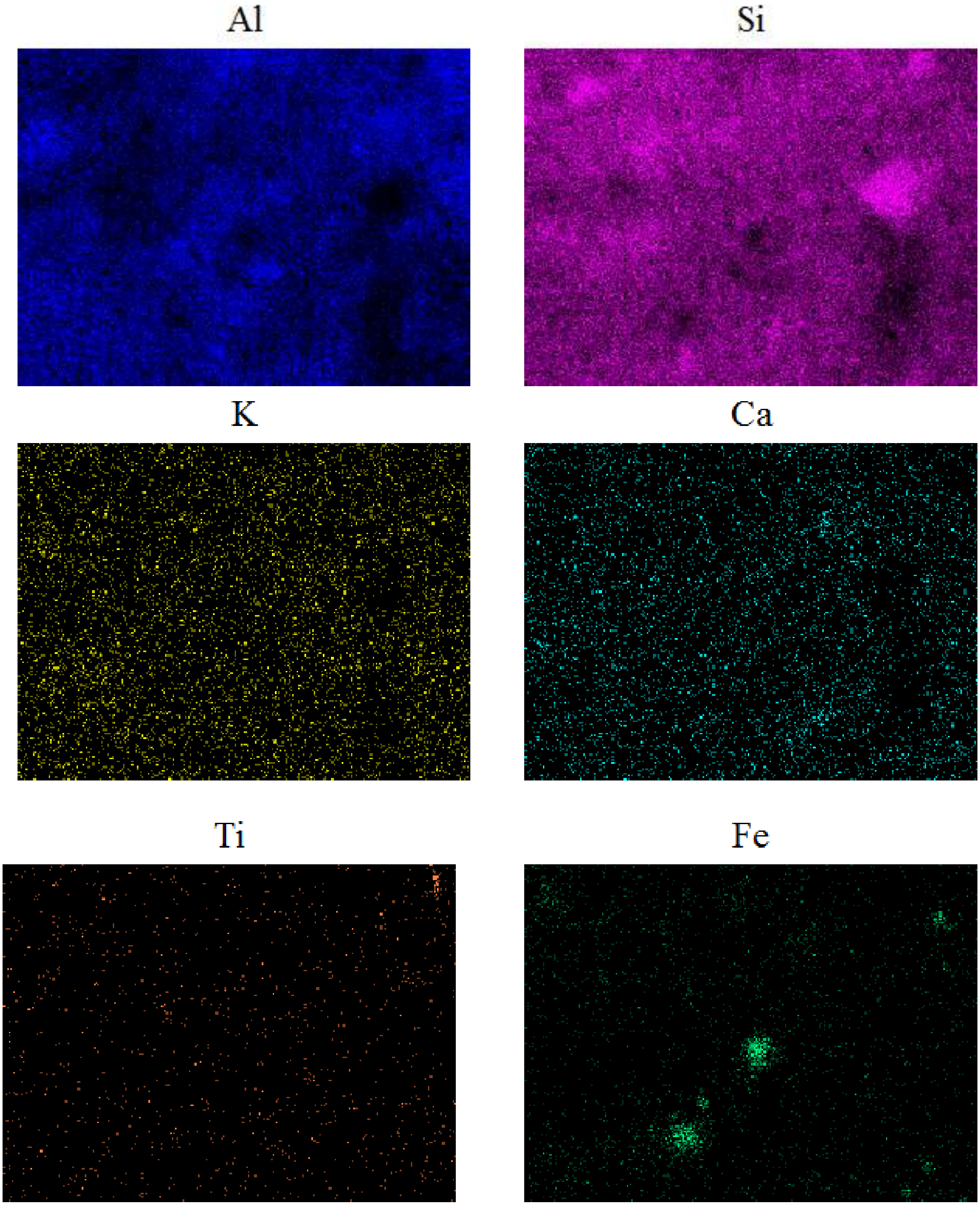

Figure 9: The occurrence of particular elements in the area presented in Figure 7.

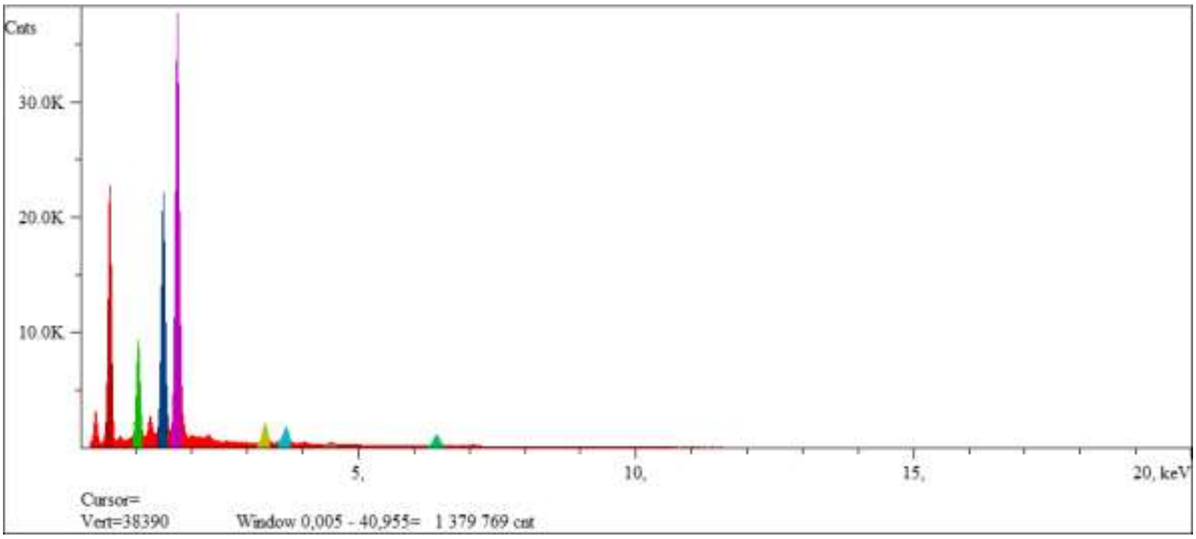

Figure 10: The occurrence of particular elements in the area presented in Figure 7 (EDS).

3.2 Compressive strength of geopolymer composites

The compressive strength test were made for minimum 15 samples. In the Figure 11. and 12. there are presented average results. The 7-days samples were stored in ambient condition. The 28-days samples were sunk after preparation and was stored underwater. During the visually assess for 28-days samples it was observes an efflorescence on the surface the samples (there was no efflorescence on the surface the samples stored in ambient condition even longer than 28-days).

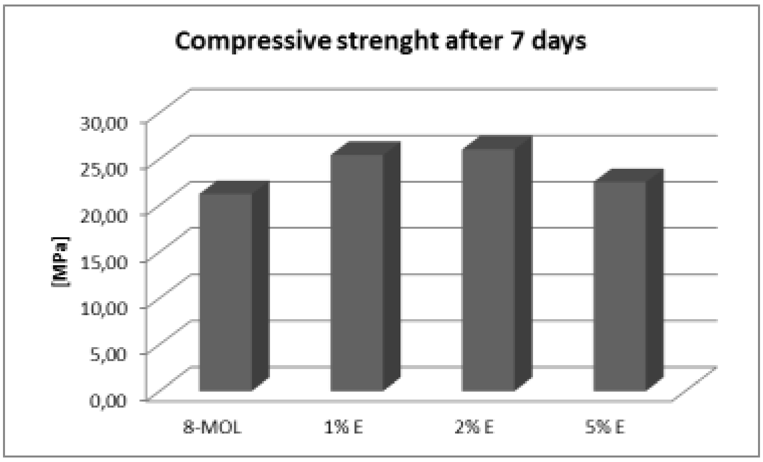

Figure 11: Compressive strenght test after 7 days.

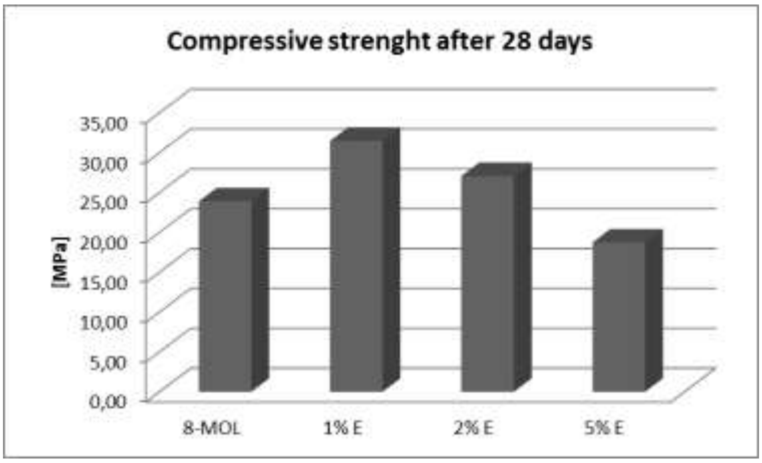

Figure 12: Compressive strenght test after 28 days.

4 DISCUSSION AND CONCLUSIONS

Geopolymers composites reinforced with glass fibers have been manufactured and characterized. The samples were prepared using sodium promoter and fibres addition for 1%, 2%, 15% and 5% by mass of the composite (8 M). The research were made for reinforced samples and 8M geopolymers (for comparison).

The scanning electron microscopy analysis proved that the fibers are coherent wit geopolymer matrix. It was possible also observe that glass fibers reduce a cracks propagation in the material. For same samples could be notice some fiber agglomerations. It was connected with a concomitant reduction in mechanical properties of the composites.

Optimum enhancements in compressive strength were achieved for composites containing 1 - 2% glass fibers. It was confirmed in different condition (samples stored). The samples which were stored underwater it was observes an efflorescence on the surface. However, they did not lose a mechanical properties.

Nowadays geopolymer composites are the most promising alternative for the environment compering to the ordinary Portland cement for different application. Thanks to addition a fibers such as glass fibers they can be applied to new area.

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