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Sustainable management of water potabilization sludge by means of geopolymers production

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Abstract:

Alumina-containing water potabilization sludge (WPS) is one of the main wastes produced by reservoir management activities. This kind of residues, deriving from treatment processes for water potabilization, recently attracted great attention as starting raw material in the production of innovative building materials. In this study, the use of WPS as aluminosilicate source for the synthesis of geopolymers has been investigated. In particular, two different potabilization sludge deriving from the water treatment plants of two artificial water reservoirs have been selected. For both of the WPS, mineralogical (XRD analysis), physical-chemical (FTIR analysis), thermal (TGA-DSC analysis), porosimetric (BET analysis) and morphological (SEM analysis) properties have been evaluated. A thermal treatment at 650°C has been performed on the two raw sludge in order to increase their reactivity. Geopolymeric samples have been produced by the hardening of the calcined WPS in two sodium silicate solutions, differing only by concentration, and using two curing temperatures. Obtained specimens have been widely characterized from chemical, mechanical and microstructural points of view. SEM, FTIR and XRD analyses confirmed that the geopolymeric reaction effectively took place for the samples produced by using the more concentrated solution and the higher curing temperature. In general, the mechanical performances reached by the specimens, suggest the possibility of a promising reuse of WPS as raw materials for the synthesis of geopolymer based building precast components.

Keywords: Geopolymers, water potabilization sludge, waste reuse, sustainable building

1. Introduction

In the last years, a great attention has been focused on geopolymers, emerging binding materials with the potential to form a substantial element of an environmentally sustainable construction and building products industry (Duxson et al 2007a; Duxson et al 2007b). Geopolymers are synthetic alkali aluminosilicate materials produced from the reaction of a

solid aluminosilicate with a highly concentrated aqueous alkali hydroxide or silicate solution (Duxson et al. 2007b). These materials have been widely proposed as an economical and sustainable alternative to cement in different applications, such as in the military and aeronautical field, high-tech ceramic materials, thermal insulators, fire-resistant materials, protective coatings, refractory adhesives and hybrids inorganic-organic composites (Menna et al., 2013; Roviello et al., 2015; Colangelo et al., 2013), because they can provide comparable performances to traditional cementitious binders, but with the added advantage of significantly reduced greenhouse emissions (Gartner, 2004). It is well known that, in theory, any pozzolanic compound or source of reactive silica and alumina, which is able to readily react with alkali, can act as a geopolymer precursor under certain conditions (Xu and Van Deventer, 2000). In fact, the formation of geopolymers from natural minerals (Xu and Van Deventer, 2003), calcined clays (Peirce et al., 2015; Messina et al., 2017), industrial by-products (Chindaprasirt et al., 2009; Ferone et al., 2013a; Lirer et al., 2017) or a combination of them (Fletcher et al., 2005, Hu et al., 2018, Mehta and Siddique, 2018) has been widely explored. In particular, in the last decades, due to the increasing cost of raw materials and the continuous reduction of natural resources, the selection of sustainable aluminosilicate materials has become imperative (Liguori et al., 2017).

Alumina-containing water potabilization sludge (WPS) is one of the residues produced by reservoir management activities. This waste, classified by the CER code 190902, accumulated after treatment processes for water potabilization, which are based on flocculation-clarification using alumina-based coagulant, and can be used as starting raw material in the building materials industry, leading in this way to the individuation of a smart and sustainable solution to the significant environmental issue of the disposal of this kind of waste. It is well known that all the most common drinking water processing systems generate an enormous amount of residual sludge (Babatunde and Zhao, 2007) and it is enough to consider, in fact,

that a typical water treatment plant produces about 100,000 ton/year of sludge (Bourgeois et al., 2004). This means that huge amounts of water potabilization sludge are available worldwide and the use of this rapidly increasing “waste” stream in an economic and environmentally sustainable manner represents a very challenging and interesting issue. The awareness of this problem led to a series of concerted efforts aimed at beneficial reuses, in an attempt to close the loop between efficient water treatment and sustainable sludge management (Babatunde and Zhao, 2007; Ahmad et al., 2016; Bratina et al., 2016). For example, in recent years, WPS has already been proposed in the production of bricks (Huang et al., 2005; Ramadan et al., 2008), ceramics (Kizinievič et al., 2013), cement with role of alternative raw material (Kikuchi, 2001; Lin and Lin, 2005), inorganic binder-based composites (Rodríguez et al., 2010; Huang and Wang, 2013) and lightweight aggregates (Sales et al., 2011, de Oliveira Andrade et al., 2018). Another interesting possibility for the reuse of WPS is represented by the production of geopolymers. In fact, Nimwinya et al. (2016) used calcined WPS, rich in silica, as precursor in the synthesis of geopolymer materials together with another waste, such as rice husk ash. The same authors carried out also an interesting economic analysis comparing the costs of the landfilling of the waste and geopolymer production using WPS as precursor. This analysis concluded that the higher geopolymer production costs could be recovered by selling the products, obtaining also an undoubted environmental advantage.

In this paper, the use of low silica WPS as unique aluminosilicate source for the synthesis of geopolymer based building precast components has been investigated. In particular, two different potabilization sludge deriving from the water treatment plants of two different artificial water reservoirs located in the south of Italy (Liscione, Molise and Camastra, Basilicata) have been selected and their mineralogical, physical-chemical, thermal, porosimetric and morphological properties have been evaluated. Moreover, considering the

results obtained by Tantawy et al. (2015), the effect of calcination at 650°C on both of the two WPS and on the following geopolymerization processes has been evaluated as well. The geopolymeric samples produced in the present work have been widely characterized from chemical, mechanical and microstructural points of view.

2. Experimental

2.1 Selection and characterization of the raw materials

Water potabilization sludge were collected from two different water treatment plants located in the proximity of two artificial water reservoirs in the south of Italy: Liscione (Molise), named throughout the text as LiTQ, and Camastra (Basilicata), indicated as CaTQ. The two WPS were dehydrated in the plant by sedimentation and belt pressing, thus the final water content is quite low. It was measured after dehydration in oven at 105°C until constant mass and it resulted to be equal to 17% for LiTQ and 18% for CaTQ. Then the two WPS were milled in a ring mill and then the characterization of each sample was performed by means of chemical (quantitative), mineralogical, thermal and spectroscopic analyses. The chemical composition was determined by X-ray fluorescence, using a Bruker Explorer S4 apparatus. The mineralogical analysis was performed by means of a Bruker D2 Phaser diffractometer (Cu K α radiation, 10–60° 2 θ range, 0.05° 2 θ /s scan speed). The thermal and spectroscopic analyses were performed respectively by TGA/DSC analyses in the range 20-1000°C (Mettler Toledo TGA/DSC 2 STAR^e with a heating rate of 10°C/min) and FTIR spectroscopy. In particular, FTIR spectra were collected using a Jasco FT/IR-430 from 2000 to 400 cm⁻¹ with a wavenumber resolution of 8 cm⁻¹ for 100 scans and in transmittance mode on transparent pellets obtained dispersing small amounts (about 1-2% wt) of the powder samples in KBr. Considering the fact that the thermal activation can be useful for enhancing the reactivity of these starting raw materials (Tantawy, 2015), weighted amounts of both sludge were thermally treated at 650°C for 1 h. The calcination was performed using a Nabertherm

furnace with a heating rate of 10°C/min and the so calcined sludge are named throughout the text respectively as Li650 and Ca650. The morphological characterization has been carried out through SEM analysis (Phenom ProX). Particle size distribution by means of a laser particle size analyzer (Malvern Instruments Mastersizer 2000) and BET nitrogen adsorption analyses (Sorptomatic 1990) have also been performed on both raw and calcined materials in order to have a complete characterization of the two potabilization sludge before their use as aluminosilicate source in the geopolymeric samples production.

2.2 Preparation of geopolymeric samples: strength measurement and characterization

Geopolymeric specimens have been prepared adding the alkaline activator to the two calcined sludge (Li650 and Ca650) and then mixing and pouring the so obtained paste into polyethylene cubic molds (4×4×4 cm). Two different alkaline activators have been used, one is a standard commercial aqueous sodium silicate solution (SS) with SiO₂/Na₂O equal to 2 provided by Prochin Italia S.r.L. from Marcianise (Caserta), the other one is the same SS solution diluted at 25% vol with bi distilled water (SSd). The SS solution can be classified as user-friendly according to Davidovits (2013), as the SiO₂:Na₂O ratio is higher than 1.45 and to European REACH directives and regulations which suggest $R \geq 1.7$. Furthermore, chemical industries started to produce silicate solutions ready to be used for geopolymer production (such as Geosil products by Woellner) following these guidelines. The same silicate solution has been used diluted at 25% vol in order to further decrease the amount of chemicals and to improve eco-sustainability of the activator. The powdered sludge were previously weighed, dry mixed and homogenized, then the selected activating solution was added to the different dry mixtures. The liquid/solid ratios, which have been carefully chosen on the basis of our previous wide experimental experience in the geopolymer production, selected for the potabilization sludge are respectively 1.1 mL/g for Li650 and 1.0 mL/g for Ca650 and for both the activating solutions. After pouring, the samples were first vibrated for

60 s, in order to promote the removal of air bubbles entrapped in the slurries, and then stored in sealed vessels in order to ensure 100% relative humidity conditions. Three specimens for each kind of sludge and of activator have been produced and cured at room temperature (25°C), and other three for both sludge at 60°C, for 7 days. At the end of the curing period, all the specimens were removed from the molds and stored at room temperature. The specimens were then tested for compressive strength after 7 and 28 days using a Controls multipurpose testing machine (50-C1201/FR) with a load cell of 100 kN. The compressive strength (N/mm²) was calculated dividing the maximum load applied to the specimens by the area of their cross-section. Furthermore, all the geopolymeric samples were subjected to SEM observation and to FTIR spectrometry in order to investigate the main microstructural features and to verify the effective occurring of geopolymerization reaction.

3. Results and discussion

3.1 Water potabilization sludge characterization

In Figure 1, the XRD spectra of both potabilization sludge, raw and calcined, are reported. The main crystalline phases present are Quartz, Kaolinite, Calcite, Muscovite and Lisetite for CaTQ. XRD pattern of Ca650 shows that the thermal treatment leads to the disappearance of the peaks related to Kaolinite and to a significant decreasing of the peaks related to Calcite. Considering the spectra of LiTQ (Figure 1b), the main crystalline phases resulted to be Quartz, Calcite and Muscovite; Kaolinite as main clay phase can be identified too. From the spectrum of Li650 it can be noticed that the thermal treatment causes the same effect on Kaolinite and Calcite previously described, while no significant modification can be detected for the other mineralogical phases, which resulted to be more stable also at higher temperatures. The chemical composition of sludge, reported in Table 1, confirms the aluminosilicatic nature of both samples: in fact, the main oxides are SiO₂ and Al₂O₃ whose

total amounts are higher than 60% in both cases, also CaO is present even if in lower concentrations.

	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	TiO ₂	Na ₂ O	SO ₃	P ₂ O ₅	LOI
LiTQ	34.64	28.07	4.41	4.67	1.47	1.44	0.50	0.23	0.55	0.42	23.80
CaTQ	45.15	24.29	5.36	3.17	1.36	1.49	0.43	0.29	0.00	0.16	18.20

Table 1 Chemical compositions of the potabilization sludge (% wt)

Consequently, both potabilization sludge can be considered as potential aluminosilicate source for producing geopolymeric materials. Moreover, it is worth to note that both sludge showed quite low values of silicon/aluminum molar ratio, in particular it is equal to 1.05 for the Liscione one and 1.58 for Camastra. According to Davidovits (2013), the lower is the silicon/aluminum ratio of the obtained geopolymer, the higher is its mechanical strength. In particular, according to Duxson et al. (2007a), and Ferone et al. (2013b) the optimal silicon/aluminum ratio for metakaolin-based geopolymers is approximately 1.8. Considering that the alkaline activating solution does not contain aluminum at all, the availability of a precursor characterized by $Si/Al \approx 1$, similar to metakaolin, is of great value especially taking into consideration the possibility to correct the silicon/aluminum ratio of precursors rich in silica (Messina et al. 2017).

The results of the thermal analysis performed on the powdered raw sludge samples are reported in Figure 2. In the range 20–180°C, weight losses of about 5% and 10%, for LiTQ and CaTQ, respectively were recorded and related to the absorbed or weakly bound water for both sludge. It is possible to identify two other weight losses between about 200 and 700°C (20% for LiTQ and 13% for CaTQ) that can be ascribed to the structure collapse of the clay phases with the consequent dehydration of aluminosilicate species and to the CO₂ evolution from carbonates present in both sludge. Furthermore, both WPS contain an organic fraction,

whose presence is evidenced by the recorded weight loss between 300 and 400°C (Figure 2) and confirmed by an exothermic effect in the DSC analysis (not reported) in the same temperature range. Moreover, no significant weight losses can be detected over 750°C for both WPS.

Taking into consideration the results of the thermal analysis, WPS have been thermally treated at 650°C and these calcined sludge have been used in the geopolymer production. The thermal treatment has been performed in order to promote the required thermal activation of clay minerals (Ferone et al., 2015) and the removal of the organic phases present.

In order to improve the chemical characterization of the starting materials for the production of geopolymeric samples, FTIR spectroscopy was performed on the calcined potabilization sludge. The spectra are reported in Figure 3. It is possible to easily identify two absorption bands located respectively at about 1075 cm⁻¹ for Li650 and at about 1070 cm⁻¹ for Ca650, related to the overlapping of T-O-Si (T=Al or Si) asymmetric stretching typical of aluminosilicate species (Davidovits, 1991). Other significant absorption bands are those related to the symmetric stretching Si-O-Si at 795 cm⁻¹ and the one connected with the Si-O bending located at around 460 cm⁻¹ (Deshmukh et al., 2012); they are both visible in the spectra of the two calcined sludge as further confirmation of the results obtained from mineralogical and thermal analyses about the presence of aluminosilicate phases in the materials. The bands at around 1640 cm⁻¹ are assigned to the bending vibrations of -OH groups in interlayer water molecules (Ferone et al, 2015). Moreover, the presence of an absorption peak at around 1435 cm⁻¹ is likely attributable to carbonate species (Shahraki et al., 2011).

From the SEM images at different magnifications of Li650 and Ca650, reported in Figure 4, it is possible to observe, in both cases, the presence of a quite compact microstructure characterized by clusters of particles with different dimensions. In particular, for Liscione

sludge, it is more evident the coexistence of coarse and medium-fine particles with irregular shapes and rough surfaces.

The last stage of the preliminary characterization of the sludge has been completed evaluating first the particle size distributions and then the respective porosimetric properties and specific areas for raw and calcined material. The results obtained performing laser granulometry, in terms of both absolute and cumulative volume, are reported in Figure 5. CaTQ essentially shows an unimodal particle size distribution centered at around 71 μm (Figure 5a) with $d_{50}=29 \mu\text{m}$ and mean Sauter diameter $d_{Sauter}=6.5 \mu\text{m}$. There are no particles coarser than 550 μm . Moreover, from the comparison between CaTQ and Ca650, it appears that the thermal treatment does not significantly affect the particle size distribution: the values of d_{50} and d_{Sauter} remain about the same (respectively 26 μm and 6.5 μm). Considering the granulometric curves of the Liscione sludge (Figure 5b, sample LiTQ), it is possible to notice the presence of a more dispersed particle size distribution. In particular two main peaks can be identified, one located at around 0.8–2 μm and the other one at around 50 μm , with $d_{50}=11 \mu\text{m}$ and $d_{Sauter}=2.4 \mu\text{m}$, also confirming the observations obtained from SEM images (Figure 4b). The calcination treatment (sample Li650 vs. LiTQ) affects the particle size distribution causing a shift towards coarser values of particle diameters. The particle size distribution of the Li650 sample looks more homogenous than the one of the raw sludge and characterized by higher values of d_{50} and d_{Sauter} , which result to be equal respectively to 18 μm and 3.4 μm .

Porosimetric features and specific surface areas for raw and calcined sludge have been evaluated performing BET nitrogen adsorption analyses. Figure 6 shows the specific cumulative pore volume distributions for both raw and calcined water potabilization sludge. It is possible to observe that the non-calcined Camastra sludge (Figure 6a, CaTQ) shows a value of total specific cumulative porosity equal to 267 mm^3/g , with 34% of microporosity, 54% of mesoporosity and 12% of macroporosity (as reported in Table 2). For Ca650, it is possible to

conclude that the thermal treatment at 650°C leads to the reduction of the micropores amount (30%) in favor of mesopores (57%) and macropores (13%) with a consequent small increase of the total porosity from 267 mm³/g to 288 mm³/g (see values reported in Table 2). Furthermore, this leads to the decrease of the BET surface value from 139 m²/g for CaTQ sludge to 131 m²/g for the calcined one (Table 2). LiTQ, Figure 6b, is characterized by the presence of a porosity of larger dimensions, in particular with 28% of mesoporosity and 67% of macroporosity. It exhibits also lower values of BET surface compared to those of the Camastra sludge (Table 2). For Li650, the calcination process causes a change in the pore size distribution. The macroporosity halved (34%) and the mesoporosity doubled (56%) compared to LiTQ (see Table 2). Microporosity increases from 5% to 10% in the calcined sludge. Moreover, it can be noticed a consequent significant decrease in the total cumulative pore volume values from 435 mm³/g for the raw sludge to 178 mm³/g for the calcined one.

Sample	BET surface area (m²/g)	Total porosity (mm³/g)	Microporosity (mm³/g)	Mesoporosity (mm³/g)	Macroporosity (mm³/g)
CaTQ	139	267	91 (34%)	145 (54%)	31 (12%)
Ca650	131	288	86 (30%)	163 (57%)	39 (13%)
LiTQ	38	435	20 (5%)	124 (28%)	291 (67%)
Li650	33	178	17 (10%)	100 (56%)	61 (34%)

Table 2 BET surface areas and porosimetric features for CaTQ, Ca650, LiTQ and Li650

samples

From the results obtained by this wide preliminary characterization of the raw and calcined WPS, it is possible to deduce that Liscione sludge will be likely characterized by a higher reactivity compared to Camastra one. Considering its pore and particle size distribution, Liscione sludge showed a lower particle size and the presence of a higher percentage of total macro- and meso-porosity which can be considered two parameters that positively affect the

sludge activation in alkaline environment. In fact, usually finer powders are characterized by higher reactivity and the presence of porosity of larger dimensions can likely improve the impregnation of the powder by the activating solution.

3.2 Geopolymeric samples characterization

The results of the compression tests performed after 7 and 28 days on the geopolymeric samples produced from the calcined water potabilization sludge are reported in Table 3.

Sludge	Curing conditions	Activating solution	σ_c (MPa)
Li650	7 d 25°C	SS	4.64 ± 0.11
		SSd	9.60 ± 0.40
Li650	7 d 60°C	SS	16.64 ± 0.29
		SSd	4.90 ± 0.31
Li650	28 d 25°C	SS	7.20 ± 0.33
		SSd	10.78 ± 0.31
Li650	28 d 60°C	SS	15.24 ± 1.50
		SSd	6.38 ± 0.58
Ca650	7 d 25°C	SS	3.95 ± 0.06
		SSd	6.56 ± 0.22
Ca650	7 d 60°C	SS	4.80 ± 0.82
		SSd	3.50 ± 0.17
Ca650	28 d 25°C	SS	8.00 ± 0.13
		SSd	8.28 ± 0.12
Ca650	28 d 60°C	SS	10.25 ± 0.67
		SSd	3.93 ± 0.31

Table 3 Compressive strengths (σ_c) of the produced geopolymeric specimens

The specimens showed acceptable compressive strength values already after 7 days, providing evidence of a rapid strength development, typical of geopolymer based materials. Considering the compressive strength values obtained after 28 days, the obtained geopolymers resulted to

be suitable for the production of non-structural building precast components. Moreover, the geopolymers obtained using the calcined Liscione sludge as raw material generally showed the best mechanical performances, exhibiting the better values of compressive strength. This can be ascribed to the different pore and particle size distribution of the two sludge, which are characterized respectively by a higher percentage of macro- and meso-porosity and by finer size in the case of the Liscione sludge. Moreover, it is worth to note that all the geopolymeric samples produced using the diluted silicate solution (SSd) and cured at room temperature showed higher values of compressive strengths than the equivalent samples obtained using the standard sodium silicate solution (SS) as activator. This can be considered a consequence of the fact that the diluted silicate solution resulted to be more fluid, because of its higher amount of water, while the non-diluted solution is more viscous. So, the presence of a more fluid activator allows to obtain a less viscous final geopolymeric slurry which resulted to be more castable and characterized by a reduced number of embedded air bubbles. Consequently, a lower amount of pores and voids are present in the solid geopolymeric matrices whose higher final compactness explains the better mechanical properties observed.

SEM analyses have been carried out in order to deeply investigate the different mechanical behavior of the produced samples examining their microstructures. SEM images of the samples produced starting from Ca650 show the presence of unreacted lamellar particles likely bonded by the hardened silicate solution for samples cured at 25°C (Figures 7a and 7c). This consideration is supported by the results of the EDS analysis reported in Figure 8. In fact, the EDS analysis performed on a particle, gives a Si/Al molar ratio of 1.13 and a Na/Al molar ratio of 0.41. The same analysis performed on a matrix point gives Si/Al molar ratio of 8.69 and a Na/Al molar ratio of 4.70. The ratios calculated at the two points are very different and the extremely low Al concentration in the matrix is a clear indication of scarce dissolution of the sludge in the sodium silicate solution. In the case of the sample obtained using the

diluted silicate solution, unreacted particles are less numerous after 60°C curing (Figure 7b), though anyway the EDS analysis (not reported) gives very high Si/Al and Na/Al ratios for the matrix (3.8 and 5.4 respectively), but the presence of a large number of cracks and fractures can be observed. Cracking can be ascribed to the shrinkage due to the evaporation of water both residual from the activating solution and produced by the polycondensation process due to geopolymerization. The presence of fractures is likely the reason why the compressive strength resulted to be lower compared to the sample cured at 25°C. Finally, for the sample produced using the SS solution and cured at 60°C (Figure 7d), it is possible to observe the presence of a glassy and homogeneous matrix likely due to a higher degree of polycondensation related to the higher curing temperature and alkalinity of the activating solution.

As for Li650, the absence of unreacted particles and the presence of a homogeneous and glassy matrix is evident for all samples (Figure 9). Even in this case the EDS analysis supports this consideration. In fact, the EDS analysis performed (not reported) on the matrix of a sample obtained with diluted solution and cured at 25°C gives a Si/Al molar ratio of 2.33 and a Na/Al molar ratio of 2.10, very similar to those obtained for the sample with concentrated solution and cured at 60°C, 2.03 and 1.50 respectively. Considering the specimens obtained by using the diluted solution (Figures 9a and 9b) an extensive fracturing of the sample cured at 60°C is evident, that is likely responsible of the lower compressive strength of this sample compared to the one cured at 25°C. In the case of Li650 samples obtained by using concentrated solution, an extensive fracturing is evident in both samples (Figures 9c and 9d). The higher compressive strength of the sample cured at 60° can be likely explained by considering a higher strength of the geopolymeric matrix due to a higher geopolymerization degree.

In order to further investigate the produced samples, XRD analyses have been performed in particular on the three geopolymeric samples which showed the highest values of compressive strength (Li650 7 d 60°C SS, Li650 28 d 60°C SS and Li650 28 d 25°C SSd). The spectra obtained are reported in Figure 10 and evidenced the presence of several hydrated aluminosilicate species. In particular, the two samples cured at 60°C starting from Li650 for 7 and 28 days, respectively (Li650 7 d 60°C SS and Li650 28 d 60°C SS) showed the presence of peaks attributable to crystalline Zeolite A, whose crystallization is very likely to occur in this system owing to the low Si/Al ratio (Ferone et al. 2013b). These peaks result to be completely absent in the XRD spectrum of the geopolymer cured at 25°C for 28 d (Li650 28 d 25°C SSd), probably because the crystallization of zeolitic phases from alkaline activation of different aluminosilicate species was reported in the literature (Chandrasekhar and Pramada, 2008) only at higher temperatures. It is possible also to notice the presence of calcite in all the spectra: this can be due to the carbonation of some residual calcium hydroxide at both curing temperatures.

In order to verify the extent of the geopolymerization reaction, FTIR analysis has been performed on the geopolymeric specimens cured at 60°C. FTIR spectra are reported in Figure 11 and confirmed that the geopolymerization reaction effectively took place for both potabilization sludge, even if with slightly different polycondensation degrees. In fact, it is possible to observe the presence of a shift in the absorption bands related to the T-O-Si asymmetric stretching, located at 1075 cm⁻¹ for Li650 and 1070 cm⁻¹ for Ca650 (see Figure 3), towards lower values of wavenumbers, respectively to 1000 and 1020 cm⁻¹ (Davidovits, 2013).

Moreover, a further confirmation of the occurred geopolymerization can be found out in the modification of the spectra in the range 600–800 cm⁻¹ related to Si–O–Al vibrations (Chandrasekhar and Pramada, 2008; Demortier et al., 1999; Akolekar et al., 1997; Duxson et

al., 2005). The peaks in this range are typically associated to geopolymeric and zeolitic phases. The presence of zeolitic phases has been previously confirmed by XRD analyses. From the previous discussion, the following considerations can be done: the mechanical strength of the samples is influenced by 1) the reactivity of the precursor; 2) the integrity of specimen. The higher is the reactivity, the higher is the compressive strength, but the higher is the shrinkage and consequently the fracture extension. These two contrasting phenomena, together with the results obtained by porosity and granulometry analyses, can reasonably explain the different mechanical behavior of the examined samples as the Ca650 sample results less reactive than Li650 and the curing at 60°C in some cases negatively influences the compressive strength introducing extended micro fractures in the specimens.

Conclusions

Water potabilization sludge (WPS) can be considered as one of the main waste produced by water reservoir management activities. In this paper, the possibility of using WPS, deriving from two different treatment plants in the southern Italy, as aluminosilicate precursor in the production of geopolymers has been proposed. WPS Camastra and Liscione have been widely characterized in order to verify in particular if their chemical compositions and properties can make them effectively suitable to undergo a geopolymerization process. The chemical and mineralogical analyses confirmed the mainly alumino-silicate nature of both potabilization sludge, and so geopolymeric samples have been produced using the two calcined sludge and selecting different operating and curing conditions. FTIR, XRD and SEM-EDS analyses, performed on the samples produced from both WPS, confirmed that the geopolymeric reaction effectively took place for both sludge in the case of concentrated solution and curing at 60°C. Moreover, all the specimens showed acceptable values of compressive strength after

7 days. In particular, the samples obtained using calcined Liscione sludge exhibited the best mechanical performance showing better values of compressive strength because of the higher reactivity due to its pore and particle size distribution and further confirmed by the microstructures observed. In conclusion, considering the mechanical performances reached by the geopolymeric samples produced, the possibility of a promising and concrete reuse of the investigated WPS as raw materials for the production of geopolymer based innovative building precast components (bricks or tiles) can be successfully suggested. However, particular attention must be paid to the activating solution and curing conditions adopted. This approach of using secondary raw materials, deriving from other industrial processes in the production process of sustainable building materials, represents one of the smartest and most environmentally friendly solutions to the significant environmental issue of the disposal of different kinds of industrial wastes.

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