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# A FLIPPED CLASSROOM EXPERIENCE: TOWARDS THE KNOWLEDGE OF NEW ECOFRIENDLY MATERIALS NAMED "GEOPOLYMERS"

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Abstract. Technological advances have impacted almost every facet of modern culture and even in the educational methodologies. As new technologies become available, they are often embraced in educational innovation in an attempt to enhance traditional instruction. To this purpose, the “flipped classroom” is a learning model in which content attainment is shifted forward to outside of class, then followed by teacher-facilitated concept application activities in class. The constructivist approach, realized through an active-learning style of teaching, is more important respect to the order with which the teacher participated in the learning process. In this respect, the goal is to provide an alternative teaching approach on environmental issue. In particular, thanks to active learning (flipped classroom) it is possible to know and to appreciate a new *eco-friendly* material named to “Geopolymers”. One of the most important environmental advantage that can be attributed to this material is represented by the lower energy requirements for its production. Thus, this material could represent a potential tool able to mitigate the environmental pollution. In this regard, the geopolymers could provide a possible solution to wastes reuse as a resource to scale down the demand for extraction of new resources. This paper looks at some positive aspects of technology and waste treatment, and deals with the production of innovative building materials obtained by waste recycling known as geopolymers. Specifically, it is important to highlight the possibility of using wastes characterized by high silica and aluminum amounts as raw materials, particularly suitable to produce geopolymers by chemical activation with alkali. This is a useful method to improve hazardous-waste management and to reduce health and environmental issues due to the strong capability of make inert hazardous waste. This solution confirms the importance of re-manufacturing, reusing and recycling and, moreover, making a waste a new raw material and helps to move toward a more circular economy where wastes become negligible and further natural resources are used in an efficient and sustainable way. The proposed topic is addressed to students and aims to arouse their interest in the fields of the environmental protection and waste management, but overall it gives the perspective of natural resource preservation, and a most efficient way of their use without depleting the planet’s resources.

## 1. Introduction

Commonly, the geopolymers can be defined like an inorganic three-dimensional polymers obtained by the alkali activation of aluminosilicate $(SiO_2 and Al_2O_3 > 80 weight\%)$ powders (Fig.1). Raw materials used in the synthesis of silicon-based polymers are mainly rock-forming minerals of geological origin, hence the name: geopolymer. Joseph Davidovits coined the term in 1978 (Davidovits 1978) and created the non profit French scientific institution (Association Loi 1901) Institut Géopolymère (Geopolymer Institute).
Generally, these new materials are generated during the first step of alkali activation and present amorphous gels in which the silicate and aluminate units occur in a 3D-connected tetrahedral framework after the polycondensation process. Usually, the aluminosilicate powders and alkaline solutions (*e.g.*, NaOH and KOH) can be appropriate raw materials for geopolymers preparation, based on their chemical compositions. However, besides the natural aluminosilicate powders (*e.g.*, laterites, pumices, kaolin, metakaolin and volcanic ash), many non-hazardous inorganic wastes have been used in geopolymerization procedures, as already demonstrated by several studies carried out over the last decades. For instance, the alkali activation of aluminosilicates has been successfully obtained using different wastes as incinerator bottom ash (Kamseu *et al.* 2009), porcelain stoneware polishing sludge (Lancellotti *et al.* 2015), natural stone cutting sludge, waste glass (Andreola *et al.* 2016), natural stones cutting (Memon *et al.* 2013), ladle slags (Bignozzi *et al.* 2013), bagasse ash (Tippayasam *et al.* 2014), and rice husk ash (Kamseu *et al.* 2016).

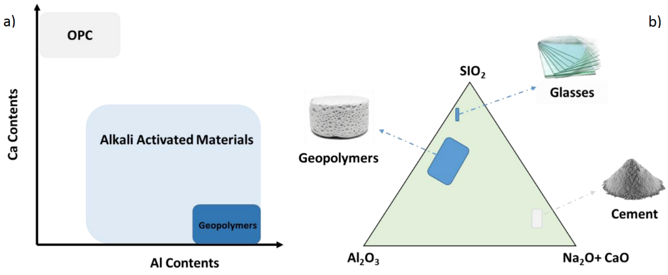

FIGURE 1. a) Groups and subgroups of materials based on Ca and Al contents - b) Comparison between cements and geopolymer chemical compositions.

Figure 1 shows the Alkali-activated materials (AAMs), and as their subgroup the so-called geopolymers, generally known as alternative $low-CO_2$ binders, which can be used instead of Portland cement in construction (Provis 2014, 2018).Additionally, the geopolymers are important tools in promoting the circular economy, by the conversion of many inorganic wastes into useful products (Mehta and Siddique 2016). The geopolymers include simpler and less-energy intensive preparation process compared to similar materials, such as ceramics or synthetic zeolites, and useful properties: for instance, high mechanical strength (**12**), good durability (Pacheco-Torgal *et al.* 2012) and ion-exchange capacity (Bortnovsky *et al.* 2008; O'Connor *et al.* 2010; Skorina 2013). All wastes are identified by a six-digits code, the list of which is divided into 20 classes. Each of waste group arises from the same production cycle (EWC 2002). Within the list, any hazardous waste is marked with an asterisk. ‘Dangerous substance’ includes any substance classified as dangerous according to Directive 67/548/EEC (Council Directive 67/548/EEC of 27 June 1967) and following amendments: this classification is subject to updating, as the research and knowledge in this field are constantly changing. The reduction of waste quantities is strictly related to the adoption of European environmental regulation (2008/98/EC) that establishes the principles of responsibility from producers to customers, able to increase the environmental sustainability, according to safe management.

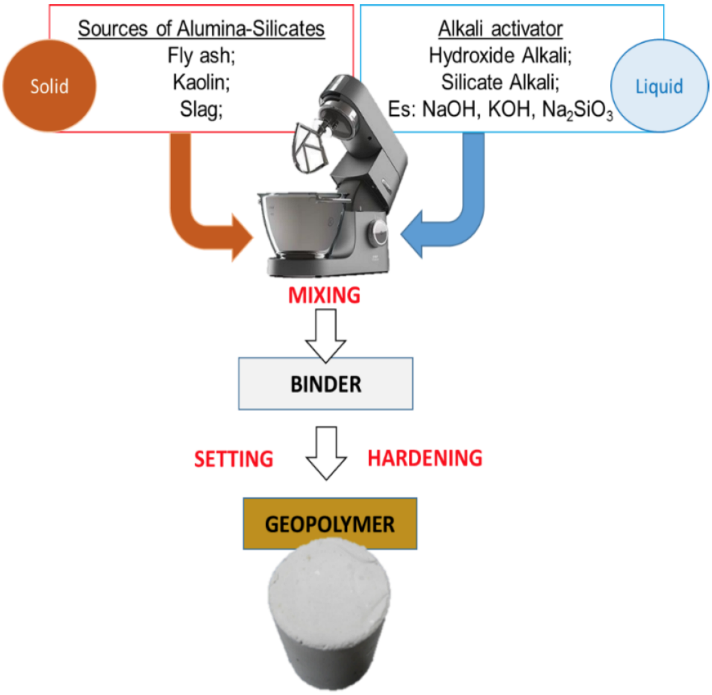

FIGURE 2. Flow chart of geopolymeric binder. Natural materials (volcanic ash and pozzolanic powders) and industrial, agricultural and urban wastes subjected to thermic treatments can be considered raw materials with aluminosilicates in geopolymer productions.

Figure 3 summarizes the most important strategies to move towards a ‘recycling society’, trying to avoid waste and to use them as resources.

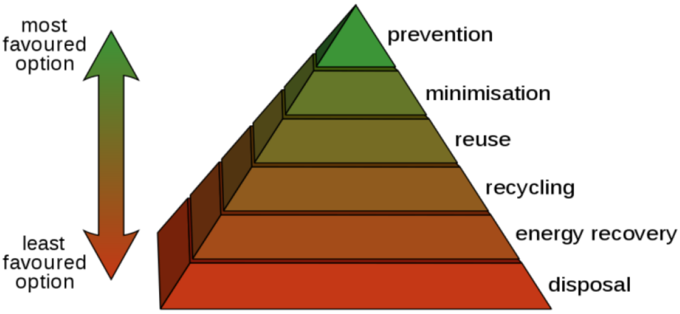

FIGURE 3. Waste management hierarchy.

Another way to lower the waste production derives from the use of Best Available technologies (BAT) that constitute the most technologically advanced management systems. In relation to different origins (urban and special waste) or to the hazardous characteristics, wastes can be classified in hazardous (marked by asterisk) and non-hazardous. With the aim to add knowledge to students, this paper exhibits an overview of new kinds of eco-friendly materials obtained by wastes recycling that otherwise, would be disposal in landfills. Moreover, in order to enhance the environmental sustainability, as established by the European Commission rules, this review promotes some examples of geopolymers able to produce, by the inertization procedures, environmental and commercial advantages.

FIGURE 4. Overview of the most important application fields of geopolymers.

## 2. Chemical of geopolymerization process

Geopolymers consist of a polymeric Si–O–Al 3D framework, predominately amorphous, with two parameters (Si/Al and Na/Al molar ratios) able to affect the stability and the mechanical properties of their nanostructures (figure 5). Concerning the Na/Al ratio, the $Na^+$ ion contributes to polymerization process, conversely $OH^-$ ion contributes to dissolution step of $Si4^+$ and $Al3^+$. The particular 3D framework exhibit by geopolymers make also easier the anions entrapment in aluminosilicate matrices. With Na/Al equal to 1 even the inertization of hazardous inorganic wastes into the geopolymeric matrix can be realized.

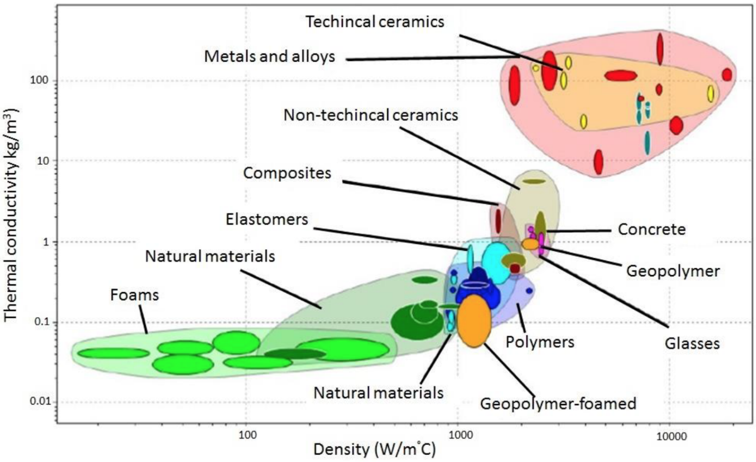

FIGURE 5. Ashby diagram that represent the different classes of materials (Geopolymers in orange) according to their compressive strength. (Fonte C. Leonelli, M. Romagnoli, "Geopolimeri. Polimeri inorganici chimicamente attivati", ICerS,2011).

## 3. Evaluation of inertization degree

In order to demonstrate the effectiveness of heavy metals inertization the leaching tests must be performed because, only in this way, it is possible to confirm the goodness of these procedures. The immobilization of heavy metals (Sb, As, Cu, Cd, Cr, Ni, Se, Pb, Hg, Te, Tl, Sn, Cr "VI") contained, in pure form or combined with other elements in chemical compounds, in hazardous wastes can be obtained by different treatments: heat or cold processes.

## 4. Overview of inertization techniques

The inertization techniques allow a reduction of environmental impact that, in terms of wastes dangerousness, involves a lowering of potential pollution degree preventing or minimizing the transfer of pollutants into the environment. Only decreasing the area available to leach, the non-hazardous wastes become suitable for subsequent phases (landfilling or recovery). In Table 1 are reassumed the processes of inertization. The choice of the

| Heat treatments | Cold techniques (stabilization/solidification) |
|---|---|
| Vitrification | Inorganic:cement/silicates, lime, clay |
| Glass-ceramization | Organic reagents: thermoplastic, resins, polymers |
| Plasma torch | |

TABLE 1. Hot and cold inertization techniques.

appropriate treatments, able to enhance the environmental sustainability, depends on wastes composition and on their production cycles.

The immobilization methods can be roughly divided into two categories:

(1) Heat treatments techniques adopt high temperatures for thermal destruction of the wastes. These techniques are vitrification, glass-ceramization (1300-1500°C), and with plasma torch (7000-13,000°C depending on the type of torch used).

(2) Cold processes (25-150°C) obtained with hydraulic binders based on inorganic (*e.g.*, cement, lime, clay) or organic (*e.g.*, thermoplastics, macro-encapsulating compounds, polymers) reagents.

**4.1. Cold inertization techniques: geopolymers for inertization of heavy metals.** In this paper only the cold treatments were considered as inertization techniques because they assurance a low $CO_2$ fingerprint. As previously described, the surface reactivity is responsible for the bond that is formed between waste particles and aluminosilicate matrix immobilizing the heavy metal ions. Therefore, the nature of the waste, in terms of mineralogy, alumina and silica contents, particle size, surface area and morphology, significantly affect the reactivity of the waste itself. To assess the real effectiveness of the immobilization abilities of heavy metals, several authors have evaluated, through leaching tests in different solvents, the performance degree in encapsulation of heavy metals (Pb, Cu, Cr, Cd) using kaolin, metakaolin and cement added with coal fly ash and/or blast furnace slag like precursors (Palomo and Palacios 2003a; Phair *et al.* 2004a; Hanzlíček and Steinerova 2006a; Xu *et al.* 2006; Zhang *et al.* 2008a,b). The leaching process is a very complex phenomenon, which requires the strict control of several parameters including particle size distribution, pH of eluating solution, temperature, contact time, stirring, liquid/solid ratio, etc. The leach of wastes can be due to degradation and disruption of the matrix or their release from an intact matrix. In this overview, have been considered only results produced by leaching tests on geopolymeric matrix insufficiently degraded.

**4.1.1.** *Lead, copper, chromium and cadmium.* The lead immobilization is strongly controlled by different factors one of which is the influence exerted by the type of cation present in alkaline solution used to activate the matrix and the waste. In this case, it is reasonable to hypothesize a key role of sodium in the leaching process of Pb-containing geopolymer. The effectiveness of Pb immobilization varies significantly and it mostly depends on pH of alkali solutions. In this respect, the most effective lead immobilization is obtained when using NaOH solution, which ensures a higher pH rather than the sodium silicate, composed by the mixture of the two solutions that presents an intermediate value of pH (Phair and Van Deventer 2001; Phair *et al.* 2004b). Instead, copper (Cu) is immobilized with less efficiency due to its smaller ionic radius, that makes it more mobile, facilitating the diffusion and leaching processes, for example with respect to Co and Ni (Hanzlíček and Steinerova 2006b). A similar behavior to Pb has been observed, however, also for copper: again the activating solutions containing sodium show a higher efficiency than those with potassium. Concerning to chromium, it is presents in many types of industrial wastes and is very dangerous in form of Cr (VI). Furthermore, it has been observed that the introduction of Cr (VI) into a Portland cement has a deleterious effect on the mechanical properties. In particular, when CrO3 is added in Portland cement with coal ash the setting and the mechanical performance of this material are significantly inhibited (Palomo and Palacios 2003b). On the contrary, when the insertion occurs in a matrix of blast furnace slag through alkaline activation, the immobilization results effective and produces an improvement of the mechanical properties of the materials. Other variables able to affect the immobilization of heavy metals are represent by the concentration of the alkaline solutions and by the curing time. These parameters play a key role, such as confirmed by Xu *et al.* (2006), in entrapment of toxic inorganic elements in geopolymeric materials (based on metakaolin and coal ash). The effectiveness of inertizing of Pb, Cr and Cd is evaluate with static tests in acid (sulfuric acid to pH 1), saline $(Na_2CO_3\ and\ MgSO_4)$ and in distilled water because the leaching resistance of heavy metal containing geopolymers strongly depends on heavy metal natures and aggressive components of the leaching solution. $H_2SO_4$ leaching in general shows the highest rate of metals release than the other leach solutions tested.

**4.1.2.** *Arsenic.* Arsenic is particularly important due to its high toxicity and solubility and the ease with which it is found in various waste streams. Arsenic introduced in the form of complex waste in geopolymers highlighted only partial effectiveness. Some authors have shown that arsenic contained in coal fly ashes is leached more when the ashes are in geopolymer with respect to the ashes on their own (Alvarez-Ayuso *et al.* 2008). The use of mixed systems based on blast furnace slag, rich in calcium, and coal fly ash could represent a better solution given that calcium promotes inertization of arsenic. To reassume, many parameters can influence the immobilization of heavy metals and, among them, the pH plays an important role (figure 6). For instance, in the whole pH range the arsenic is not effectively incorporated in aluminosilicates matrices, whereas cadmium is incorporated at alkaline pH and leached at acid pH. Instead, Cr, Ni, Sn are inert throughout the pH range (Waijarean *et al.* 2014).

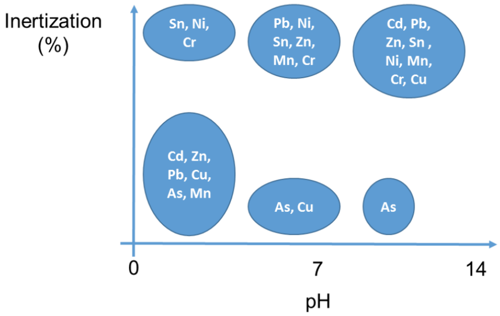

FIGURE 6. pH influence on heavy metal inertization.

**4.1.3.** *Sulphate and nitrates.* Likewise, the cold inertization techniques is also used for the inertization of anions in the geopolymeric matrices. The topic of anions immobilization has been studied by a limited number of researches that attempt to explain the interaction between anions and geopolymeric properties (Criado *et al.* 2010; Chequer and Frizon 2011; Komnitsas *et al.* 2013). For instance, the compressive strength of geopolymers is negatively affected by the presence of $NO_3^-$ or $SO_4^{-2}$ ions in the starting mixture. Both anions consume most of the available alkali activator moles and hinder the geopolymerization reactions. Thus, the quantity of the gel produced is limited and scarcely connected (Komnitsas *et al.* 2013).

**4.1.4.** *Chlorides.* Lee and Van Deventer (2002)found that chloride salts (KCl, $CaCl_2$ and $MgCl_2$) hinder the geopolymerization process induced by the activation of fly ash and kaolin. The salts, owing to their precipitation and crystallization in aluminosilicate gel which is the binding phase of geopolymers, contribute to decrease the durability of aluminosilicates matrices.

**4.1.5.** *Sulphides.* Sulphides, $S2^-$ ions, studied by Zhang *et al.* (2008b), play a critical role in the immobilization of Cr (VI) in alkali-activated fly ash matrices by reducing Cr (VI) to Cr (III). For instance, an addition of $S^{2-}$ (0.5%) as $Na_2S \times H_2O$ has been shown a high effectiveness in chromium immobilization, for at least 90 days, against attack by deionized water or by mineral salt solutions.

Probably, due to the Cr re-oxidation in highly mobile Cr (VI) species, the leaching in $H_2SO_4$ solution remains more problematic yet, but the addition of sulphide still provides a major increase in leaching resistance respect to those guaranteed by simple geopolymeric binders (Figure 7).

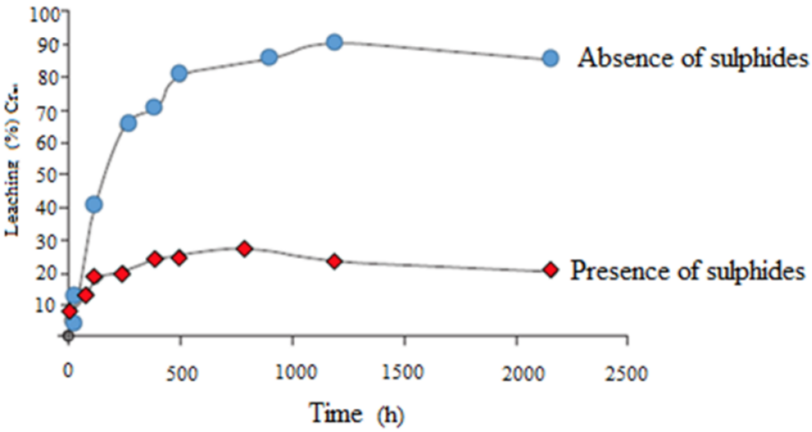

FIGURE 7. Percentage of Cr extraction in $H_2SO_4$ leaching solution (pH = 1) from geopolymers containing 0.5% Cr, added as $Na_2CrO_4$, as a function of sulphide presence (data elaborated from Zhang et al., 2008b).

## 5. Immobilization of complex solid waste

Fly ash from electric arc furnaces for steel production, containing Zn, Pb, Cr, Cd, and electrostatic precipitator and fabric filter fly ash from incineration of municipal waste containing Cd, Cr, Cu, Ni, Pb, $CO_3^{2-}$, $Cl^-$ and $SO_4^{2-}$ are classified as hazardous waste. They were mixed with blast furnace slag, coal ash and kaolin/metakaolin and activated with potassium or sodium silicate (Lancellotti *et al.* 2009; Pereira *et al.* 2009). In this context, it is expected that geopolymers with low calcium content can be a good matrix for the immobilization of this metal. Hajjaji *et al.* (2013a) have observed that the introduction of zinc in geopolymers leads to a reduction of the compressive strength but, at the same time, the setting time is not delayed as in Portland cement. Concerning to the response of the material to leaching it is a function of the leaching medium such as distilled water, acetic acid and nitric acid. For the fly ash (FA) from an incinerator it was observed that, depending on the test used, the behavior of the different matrices, based on metakaolin or Portland cement, is different. The FA activation was performed with sodium hydroxide and silicate and the leaching results show a significant decrease in the release of all metals with respect to as received ashes. However, the leaching values were lower than the limits imposed by Italian law for the landfill of non-hazardous waste (DM 30/08/2005). An important effect was evidenced for Cd, Pb and Cu, which were strongly released from both ashes, whereas they are completely immobilized in the geopolymeric matrix. Cr behaved differently since it was partially released from the geopolymer containing ash from the fabric filter. Even though Cr values were maintained below the limits for a landfill of non-hazardous waste, its release was strongly influenced by the presence of $Cl^-$ ions.

Moreover, the parameters of the production process of geopolymers can have a significant influence on the leaching of heavy metals. Concerning to the activation it was realized with potassium silicate, whereas the leaching test was performed in open and closed vessels. The ashes of urban incinerators could be subjected to pre-treatment before their geopolymerization and, in this sense, the results suggest that their washing increase the mechanical resistance and reduce the leaching fraction of Cr, Cu and Zn.

## 6. Immobilization of complex liquid waste

In the traditional ceramic industry the use of heavy metals as colorants (in liquid form) and pigments (in powdery form) is very diffused. The glazing process is the manufacturing stage during which they are mainly used; hence, waste deriving from this section of the plant is richer in hazardous compounds. One of these, in liquid form, was immobilized in geopolymeric matrix (Lancellotti *et al.* 2009). This waste is collected at the plant in liquid homogeneous form composed prevalently of aqueous solutions of metal compounds, which develop colors during the firing cycle. The colorant solution contains Fe, Mo, Mn, Co, Cr, depending on the final color, together with mineralizers and complexes. Pereira *et al.* (2009) have demonstered that the wastes incorporation, in aqueous solution, into the inorganic polymeric matrix can be successfully conducted. To this purpose, many leaching studies on consolidated materials have been carried out and shown a low release of Cr, which allows their disposal in landfill sites suitable for not dangerous wastes. Moreover, the absence of a drying pre-treatment reduces both the use of energy and handling necessary for the management of this kind of hazardous liquid waste.

## 7. Red mud hazardous waste

Potentially, another source useful to realize geopolymers is represents by red muds that constitute a major industrial waste derived by alumina refining and ensures an annual production of 21 million tons of aluminum and generates 82 million tons of sludge (Hajjaji *et al.* 2013a), this encourage the interest of many researcher as described by several studies (Cundi *et al.* 2005; Hajjaji *et al.* 2013b). Due to their risky nature, the red mud wastes are usually managed through discharge into reservoirs. Subsequently, the dewatering causes a consolidation (for gravity driven) and, successively, the reservoirs are closed by caps. Many publications (Dimas *et al.* 2009; Kumar and Kumar 2013) suggested the different potential use of inorganic polymeric materials obtained by red mud mixed with other aluminosilicates (such as fly ash if not metakaolin). For instance, in the environmental issue the aluminosilicate red muds can be used like adsorbent for cleaning of industrial gases, instead in the manufacturing sector the production of massive bricks and like lightweight aggregates in the concrete industry can be represent other reuses.

## 8. Spectroscopic techniques

In order to investigate the chemical and physical behaviour of geopolymers several techniques can be employed (Duxson *et al.* 2007; Provis *et al.* 2012). In particular, spectroscopic techniques reveal to be the most suitable ones for the characterization of the structural and dynamical properties of these systems (Caccamo and Magazù 2016, 2017a). More specifically, InfraRed (IR) absorption and Raman scattering are two not-invasive and not destructive techniques. IR technique allows to get information on the structural changes of amorphous alumino-silicates with a high heterogeneity (**75**; Caccamo and Magazù 2017b). Such a technique furnishes significant information concerning kinetics and can clarify the effect of different activators on geopolymers (Balashova *et al.* 2012; Caccamo *et al.* 2017; Magazù *et al.* 2018). Furthermore, the band assignment permits to identify the specific molecular structures and components putting into evidence that band variations and/or the presence of new bands suggest the formation of new chemical compounds (Voronko *et al.* 2006; Caccamo *et al.* 2018b; Cannuli *et al.* 2018). Raman spectroscopy, which in principle furnish the same information of IR absorption but which has different selection rules, is usually employed to characterize the different types of crystalline and amorphous silicate materials. In general, characteristic Raman peaks make reference to different SiO_4 polymerization types present in the investigated materials; for the systems we are dealing with, such a technique confirms the dominant structure of geopolymerization products, *i.e.*, type of $SiO_4$ polymerization. The Raman signal in the high wavenumber region indicates characteristic bands that can be associated to the depolymerization of $SiO_4$ tetrahedra with negatively charged Oxygen atoms neutralized by bonding with reaction entrants different from Si or Al, similar to the material of glass (Voronko *et al.* 2006; Labet and Colomban 2013). Finally, it is noteworthy to mention neutron scattering which makes reference to registering the neutron beam scattered from a sample but that in this case, contrarily to the previous techniques, *i.e.*, to IR and Raman spectroscopy, does not have selection rules (Magazù *et al.* 2011; Fenimore *et al.* 2013; Migliardo *et al.* 2013b). If the energy of the neutrons in the beam is much higher than the typical energy of the interactions of the atoms in the sample, the collision of neutrons with the nuclei depends only on the properties of the individual nuclei and therefore does not provide information about the properties of the materials. For these reasons, in order to explore what occurs inside common materials it is important that the energy of the neutrons in the beam is low, typically less than 1eV (Varga *et al.* 2008; Magazù *et al.* 2010; Magazù *et al.* 2012, 2013; Migliardo *et al.* 2013a). Among the different neutron techniques, Quasi Elastic Neutron Scattering (QENS) and Elastic Incoherent Neutron Scattering (EINS) allow to study the diffusion processes of water molecules in calcium geopolymer pastes prepared with different calcium fly ash content (Peterson *et al.* 2006; Peterson and Whitten 2009a,b; Kupwade-Patil *et al.* 2016). Furthermore, these techniques enable to know the transformation of multiphase mechanisms that occur during the process of hydration containing an aluminum silicate source like fly ash or granulated blast furnace slag ground into ordinary portland cement (Fratini *et al.* 2002, 2003; Phair *et al.* 2003).

## 9. A new teaching way: the Flipped classroom

The “flipped classroom” is one of the most recently emerged and popular technology-infused learning models. In the flipped learning model classroom teachers shift direct learning out of the large group learning space and move it into the individual learning space, with the help of one of several technologies” (instructional videos, recorded lectures, and other remotely accessed instructional items). Subsequently, teachers spend in-class time applying the material through complex problem solving, deeper conceptual coverage and peer interaction. In flipped approach, the student was given responsibility for content attainment before class and, thus, the teacher is able to facilitate the concept application through complex problem-solving and group work on items that would traditionally have been homework assignments (Provis *et al.* 2012). For example, the flipped classroom experience on geopolymers could consists of five instructional learning phases (figure 8):

1. To engage: serves to increase the interest of the students for the material proposed with the aim to make easier the process of learning; in the geopolymer issue can be useful introducing to students to a Brainstorming, key words, article of journal, video;
2. To explore: allows the students to explore the content and con¬struct their own understanding before introducing any terminology. This phase is fundamental because the students, actively engaged with materials to discover patterns, are able to make hypotheses and to build conceptual understanding;
3. To explain: it is the phase at which the teacher introduces to the students the technical terminology. In the geopolymers context, the students will be addressed to the knowledge of the several kinds of alkaline solution or of the chemical composition of precursor useful in the geopolymerization process. The knowledge of the scientific terms allows to create a potential link between their own constructions and the concept building. This phase can be accomplished by mini-lectures provided in person or remotely;
4. To elaborate: it forces the students to apply their new conceptual understanding to novel situations in order to broaden the domain and strengthen the framework of these concepts. For example, to the students can be asked to solve higher-order problems using what they had learned in the previous phases. After this

learning cycle, the students can search, based on their chemical composition, the precursor materials suitable for geopolymerization process. Therefore, nowadays, the awareness of the importance of hierarchal strategy of waste recycling represents a conceptual model able to improve and to develop a strategy of wastes reuses, which involves a reduction of environmental pollution.

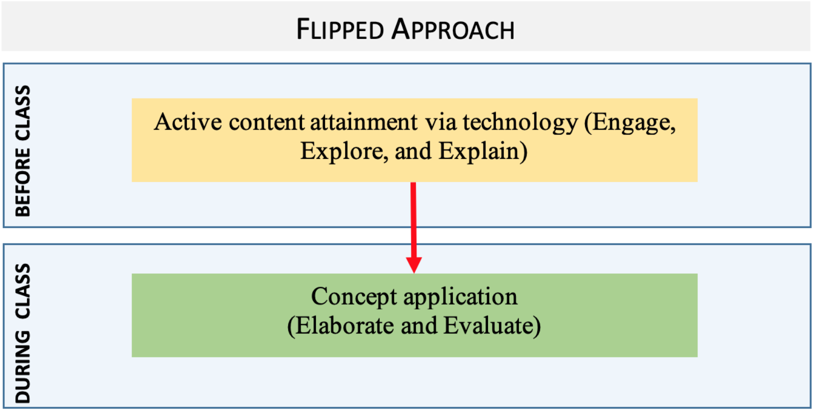

FIGURE 8. Study design. This represents the activities that would occur surrounding one class period.

## 10. Conclusions

In a flipped classroom, students are required to put in the effort to learn the materials on their own before coming to class (Kakosimos 2015; Marchalot *et al.* 2017; Caccamo *et al.* 2018a). However, due to the variation in student learning abilities and styles, in a class in which students are required to initially learn the information on their own, wide varia-tion in how much time and effort this process takes would be expected. In addition, a flipped classroom requires that students have access to technology (Lage *et al.* 2000; Lam *et al.* 2013; Caccamo and Magazù 2017c). Through the new active learning methodology, as the flipped classroom, we can try to build up a critical awareness on the importance of reuse of wastes. The active learning allows developing a several skills on *ecofriendly* materials, which potentially can be helpful and mitigate the environmental pollution. In this condition, students were first introduced to the material online during the pre-class homework assignment. However, the teacher follows the format of the learning cycle, encouraging the students to explore the phenomenon and discover patterns, offer explanations, and analyze data (engage and explore) (Kim *et al.* 2014; Jensen *et al.* 2015). To reach this aim, the students will be addressed toward the background knowledge of the chemical composition of significant sources of secondary and critical raw materials. The need to improve the reuse of wastes have been partly driven by EU targets introduced in 1994 and 2008 and later by the circular economy packages (2015). Hence, after the phase of information acquiring (Key word, key message, extract of newspaper, video), the students may be able to identify a spectrum of different wastes (urban, agricultural and industrial) that

| | |
|---|---|
| Students | Technical Institute/high school |
| Interdisciplinary links | Chemistry, Physics, Laboratory applied sciences, Ecology |
| Learning objectives | Knowledge of alternativeecofriendly materials |
| Educational goals | Developing critical awareness of environmental issues |
| Employed Materials | Video (<3min), laboratory activity files.<br>Extracts of newspaper andarticles |
| Methodologies Applied | Brainstorming,<br>Flipped classroom, cooperative learning |
| Skills | Recyclyng of wastes in geoplymer.<br>Inertization of heavy metals and organic compounds. |

TABLE 2. Sketch map of learning unit on geopolymer materials.

if reused they could reduce the environmental pollution by geopolymerization techniques. In this respect, some secondary sources of materials, also containing dangerous components (*e.g.*, heavy metals) which are actually disposed in landfill, can be used as raw materials propaedeutic to be converted in geopolymers. For this reason, the sustainable development of material with reduced environmental footprint either in manufacturing and operational phases of the material lifecycle, is worldwide attracting the construction industry. This paper briefly outlines the potential use of geopolymer technology towards green buildings and sustainable cities of the next future, with a reduced carbon footprint. These innovative materials may have an important role to reduce, recycle and reuse hazardous wastes, by inertization processes.

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