Title: Alkaline activation of natural and artificial pozzolans as binders for the improvement of waste soil

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Research program

Soil improvement techniques with binders (lime, cement) are used in several geotechnical engineering applications. A possible alternative to the use of "traditional" binders is represented by alkaline activated inorganic binders, synthesized from activated alumino-silicatic powders through an alkaline solution (mainly sodium hydroxide and/or sodium silicate). The research on the use of these binders in geotechnical practice is innovative and of great scientific and applicative interest, since in the future it allows a transition to materials with a lower impact on the environment in terms of carbon dioxide emissions.

The main chemical reactions taking place after the addition of traditional binders (lime or cement) are generally identified as ion exchange reactions (Van Olphen, 1977, Bergado, 1996, Vitale et al. 2016a) and pozzolanic reactions (Diamond and Kinter, 1965; Taylor, 1990; Sherwood, 1993; Bell, 1996; Boardman et al., 2001; Müller, 2005; Pomakina et al., 2012, Vitale et al., 2016b). In the case of alkaline-activated binders, the alkaline solution is responsible for the dissolution process of silicon and aluminium favouring the formation of polymer chains, resulting from polycondensation of silicate and aluminate ions giving rise to an amorphous or semi-crystalline three-dimensional structure (gel) of aluminosilicate hydrates with cementitious properties (Duxson et al. 2007, Provis and van Deventer, 2014).

Natural and artificial pozzolanas are the object of the experimental activity, focused on their use as a binder by alkaline activation in soil treatment. The complex nature of the physio-chemical processes considered is addressed at different scales of observation (particle scale, microstructure, volume scale), with the primary objective of quantitative evaluation of the effects of treatment and understanding the behavior of the treated material.

Recent research form the proposing group has been focused on natural pyroclastic soils from volcanic districts of Central and Southern Italy (Cecconi et al. 2010, Tommasi, Verrucci and Rotonda, 2015, Cecconi et al., 2015), fly ash from coal combustion (Knapik, Bzówka and Russo, 2014) and residual slag from metallurgical production have been studied. These studies were dedicated to the reactivity of systems in the presence of lime, to microstructural reorganization of the system, to improvement of mechanical behaviour (Cambi et al., 2016, Russo et al., 2015, Vitale 2016, Cecconi & Russo, 2013, Cecconi et al., 2010, Cecconi & Russo, 2012, Knapik, Bzówka and Russo, 2014, Knapik, Bzówka, Deneele and Russo, 2015).

The study of alkaline activation of natural and artificial pozzolana requires an experimental methodology based on a multi-scale approach. The chemical reactions taking place between the solid phase and the interstitial fluid can be detected by means of analysis techniques typical of materials science, in order to observe the chemical-physical evolution of the system over time. The change in the configuration of solid particles is observed at a higher scale, in terms of the microstructure of the solid skeleton. At the scale of the volume element, the cumulative effect of the transformations taking place at lower structural levels can be observed, in terms of hydro-mechanical behaviour, by means of geotechnical laboratory techniques.

The proposed research is divided into three main phases:

a) chemo-physical evolution of the system: experimental investigation of the reactivity of the system through the identification of the mineralogical phases and their chemo-physical evolution by means of X-ray diffractometry, differential thermal analysis, infrared spectroscopy, nuclear magnetic resonance. The objective is the qualitative and quantitative determination of the evolution of the mineralogical phases according to the treatment parameters.
b) microstructural reorganisation: experimental investigation of the evolution of the microstructure induced by the addition of binders by means of nitrogen adsorption measurements, mercury intrusion porosimetry, scanning electron microscopy, X-ray microtomography, with the objective of assessing qualitatively and quantitatively the structural reorganisation of solid particles as a result of electrochemical interactions and the precipitation of secondary phases.
c) improvement of hydro-mechanical behaviour: evaluation of the treatment effectiveness at the volume scale of samples by means of geotechnical laboratory investigations, under initial conditions corresponding to the service operating conditions of the treated soil (e.g. compaction, partial saturation), with the aim of determining the hydro-mechanical response of the treated soil as a cumulative effect of the system evolution at the microscale. The evaluation of the treatment efficiency is obtained by comparison with the geotechnical characteristics of the raw soils.
The research allows a significant advancement of knowledge in the field of soil treatment. Through the multiscale approach, the connection between the phenomena detected at the microscale and the macroscopic behaviour of the treated materials is investigated, and this is the main element of originality of the proposed research. It is also relevant the multidisciplinarity characterizing the research, from mineralogy to geotechnics to geochemistry. After the research it will be possible to rethink the use of waste materials as innovative materials, "designing" adequately their performance level according to the uses required by the construction process, intervening on the relevant factors that govern the chemio-physical evolution induced by additives.

Proposal for a PhD position

A position for a PhD will be sought for a candidate who can carry out the proposed research activity, which could validly be completed within the three years of the PhD cycle..
The work programme will include a study phase of the available literature on the most recent developments in the use of binders in soil improvement. The laboratory activities will be carried out using the equipment of DiSTAR of the University Federico II, where the PhD student will have the opportunity to acquire technical skills related to the types of investigation at different scales, from particle scale to volume element scale.
Training courses of the "Doctoral School" will be available for the PhD student at the host University, in order to improve his knowledge on different topics.
The work programme will include a period of about 6 months to be carried out in one or more UNINA's research partner belonging to GeoRes Project network, in order to allow the PhD student to learn different experimental methods and to compare himself/herself with other scholars, also in order to have the possibility to further develop his/her career.

The research is physiologically part of the activities of the H2020 MSCA RISE 2017 GeoRes project, of which the scientific responsible for the University of Naples Federico II is Prof. Giacomo Russo.