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PROPERTIES OF NON-CONVENTIONAL WASTE AND GEOMATERIALS FOR REUSE IN EXCAVATION SITES

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Abstract

Reuse and recycling of waste material from excavation and mining/quarrying activities is a global issue that received significant attention in the last decades. The links among local geology, excavation methods, spoil treatment and strategies for recycle have been identified as unavoidable in terms of early physical, chemical and mechanical characterisation of spoils. The emergence of a range of industrial waste streams and the environmental, economic and technical considerations arising from their recycle and reuse still need a comprehensive technical and validated procedure for acceptance.

This paper describes the screening tests and treatment options for material recycling in the framework of an original spoil classification system, also for specific applications, such as drainage layers, covering of dumps, rehabilitation of abandoned sites. The experience learnt by the Authors from the development of suitable methodologies for characterisation and management of spoil waste can be extended to other waste such as glass waste, gypsum, rockwool, glasswool, granulates, chipping particles, polymeric cuttings which show similarities with soils and geomaterials in terms of 'bulk behaviour.

Keywords: spoil; geomaterials; reuse; classification; waste.

Introduction

Excavation activities in civil and mining engineering operations usually involve the production of significant volumes of geomaterial waste. The development of tools and effective strategies for the reuse and recycling of such waste material has become a global issue with economic, environmental and human health and safety implications. Although the quantification of the volume of excavated rock and soil materials is not a figure explicitly provided in official statistics, an annual production exceeding one billion tonnes in Europe can be assumed, combining information from construction and demolition waste (C&DW) data and statistics on the percentage of soil over total waste (Sáez and Osmani, 2019; DEFRA, 2019).

The efficiency in reuse and recycling of muck starts from project planning. The variability of the physical state and chemical nature of excavation waste adds a significant uncertainty to such planning. The environmental compatibility of excavated materials needs to be determined even before assessing the physical and mechanical properties of the spoil materials (Kwan and Jardine, 1999), making the recycling of materials potentially contaminated by excavation techniques even more complex. (Caracciolo et al., 2019).

Geotechnical works required for transportation infrastructure projects are resource-intensive activities that have high potential for the reuse and recycle of excavation geomaterials, and primary raw resources from quarrying can be saved: a special effort is requested when combining muck production from tunnelling with aggregates supply for embankments, typical coupling in transportation engineering. The interaction among local geology, excavation methods, spoil treatment and strategies for recycle within the project have been evidenced, stressing the importance of assessing spoil properties well ahead the beginning of the excavation works.

Today the presence of a range of industrial waste streams and the environmental, economic and technical considerations arising from the recycle and reuse still need a comprehensive approach oriented towards a satisfactory level of technical performances, durability and maintenance. The experience learnt from the development of suitable geotechnical methodologies for characterisation of waste geomaterial can be extended to other waste such as glass waste, granulates, chipping particles and the likes, which show similarities with soils and geomaterials in terms of 'bulk behaviour'.

Classification system for tunnel spoil

The management of excavation spoils is claiming for a multi-criteria methodology to take into account parameters that have mutual influence: geological conditions, excavation techniques, in-situ treatment of spoil, and final destination of the material. A comprehensive classification oriented to tunnel muck reuse has been proposed in the literature (Oggeri et al., 2014; Oggeri et al., 2017).

The choice of adopted excavation method is typically influenced by local geology, length of the excavation, specific site conditions or economic and contractual considerations. Broadly speaking, excavation methods fall in four categories: (i) drill and blast, (ii) step-excavation with mechanical means, (iii) full face mechanical excavation, and (iv) special preliminary soil treatments and/or soil conditioning such as consolidation or foam injection. The excavation method influences the grain size distribution and grading of the muck, as well as the need for in-situ treatment and the need for environmental compatibility assessment.

Typical technical operations that are carried out on site for the improvement of the waste geomaterials are washing, sieving and sorting, desiccation, dewatering, crushing, lime or cement stabilisation, and compaction. For other ancillary phases, such as the grain size or grain shape control, or mineral separation, a specific treatment plant needs to be installed. The extent and complexity of in-situ treatment plant depend on the size of the project and the foreseen volume of excavated materials, the requirements for their final destination, economic considerations on local raw materials market, disposal options, local regulations and incentives for recycling.

Common reuse strategies vary according to the quality of the spoils. A possible hierarchic ranking (from the highest to the lowest added value) of the different recovering options is as follows: (i) as aggregates or raw material for industrial production when the muck is of good quality or shows ore-related interest; (ii) as material for embankments, protection works or road construction when the muck is of fair quality; and (iii) as refilling material for voids or land reclamation when muck is of low quality.

The possible end-use strategy mainly depends on the geological nature of the site, the adopted excavation method and the site treatment of the spoils. According to the final destination of the material, specific characterisation tests need to be carried out for ensuring the suitability of reclaimed geomaterial, according to technical standards and environmental constraints. Obviously, the higher the added-value pre-identified strategy for the reuse, the higher the quality required, and the stricter the characterisation campaign needs to be. Typical tests relate to the assessment of physical state (size, shape, specific gravity, roughness, void ratio, porosity) and mechanical properties (compressive strength and resistance to impact, fragmentation and crushing), as well as durability features (resistance to polishing, abrasion and wear, chemical composition and presence of hazardous substances, volumetric stability, water absorption and solubility, durability to frost and alkali-aggregate reaction for concrete preparation).

Figure 1. Four types of muck suitable for reuse: a) after Drill and Blast in granitic rock mass; b) dump of granitic chips after full face TBM excavation in granitic rock mass; c) EPBS machine excavation in hard soil – soft rock formation, with conditioning; d) dump of coarse soils after mechanized excavation in alluvium.

Environmental aspects

The reuse of excavated materials is subjected to some restrictions following environmental compatibility considerations, and therefore chemical analyses are required for a proper classification of the geomaterial and its consequent use. Contaminants and pollutants can diffuse both in ground and in the water (in the form of leachate) and a comparative analysis on both natural and reclaimed materials is necessary for assessing the concentration of contaminants also on a long term basis. Concentration of marker substances needs to be monitored over a certain time, ensuring that its desired reduction below the mandatory threshold limits is fully achieved. Full face mechanical excavation often uses additives (surfactants, polymers, bentonite slurry, tail sealing greases, anti-abrasion chemicals) that show different behaviours. While surfactants degrade in a relatively quick time (2-4 months), presence of polymers and greases might lead to concentration of contaminants. Mortars and bentonite are not affected by biodegradation processes, instead these can produce leachates. Spoils stabilisation with lime addition typically increases the pH value due to alkalinity of CaO.

Similar approach is suggested for reuse of waste coming from non conventional geomaterials like fly ashes, blast furnace slag, glass debris, plastic cuttings, micronized particles after crushing and sieving of quartz, olivine minerals, alkali activated clay minerals etc. For these materials the characterization could be easier as they are the result of a production process, without unexpected variability.

Non-conventional waste stream

The reuse of non-conventional materials has a great relevance as it is typically accompanied by savings in disposal costs as well as in the procurement of raw materials. Examples of such non–conventional materials are wooden chips, granulates, waste glass powder, out-of-shape residues from manufacturing processes or leftover from the triage of other waste after processes aimed at obtaining inert materials (so called ‘end-of-waste’).

‘End-of-waste’ status for waste stream is achieved when the waste material ceases to be considered an actual waste when specific conditions are met. Possible waste streams for which ‘end-of-waste’ specifications and criteria should be developed are, among others, construction and demolition waste, metallurgical by-products, thermal treatment residues, scrap metals, exhaust tyres, waste textiles and paper, compost, and glass. In order to reach ‘end-of-waste’ status, the waste recovery operations do not need to be excessively onerous. Often it is enough checking the waste has clear and direct utilisation strategies for fulfilling the ‘end-of-waste’ criteria.

Non-conventional materials can be originated from different streams: excavation or demolition waste from civil works; overburden and not productive geological layers from mining and extractive activities; environmental-related activities (cleaning, filtering etc.); industrial activities; quarrying production of ornamental stones. Regional or national boards usually provide technical regulations to properly follow these materials. Non-conventional waste materials share with geotechnical materials a number of features. The variability in composition, size distribution and shape of the elements of such materials can be assessed by adapting conventional geotechnical characterisation tests. The similarities between ‘bulk’ non-conventional waste materials and waste geomaterials refer to the geometric ratios, but the most important common feature is the different behaviour at small scale (laboratory) and at a large scale (worksite), which makes predictions on this latter based on evidences from the former broadly inaccurate.

The properties of non-conventional waste streams are closely connected to the processes that led to their production and nature. Element sizes, grading distribution, physical, mechanical and chemical properties and their interaction with water relate to the initial material for manufacture (i.e. the ‘geological conditions’), the industrial process that the material underwent (i.e. the ‘excavation techniques’), the post-production treatment (i.e. the ‘in-situ treatments of spoils’) (Oggeri and Vinai, 2020). The potential recycling options (i.e. the ‘final destination of materials’) have an impact on the required treatments.

Typical tests for the characterisation of non-conventional waste streams include the assessment of physical (grain size distribution, morphometry, loose and densified unit weight, and compaction parameters), mechanical (compressibility, elastic recovery in unloading, internal shear strength and shearing properties at interfaces with the geosynthetics, repose angle), and site-specific (dimensional stability, resistance at different compaction levels, real scale hydraulic permeability) properties. Other specific tests can investigate the toughness properties, freezing response, water absorption and cohesion, fire resistance. The assessment of environmental and chemical properties of the materials is of paramount importance, as well as the characterisation of leachates in terms of possible contaminations due to decomposition or biodegradation of material components. Interaction with ground water or rainwater is also to be taken into account for ensuring geometric stability of embankments and for ensuring the release of pollutants is avoided.

The legislation and technical prescriptions for these recovered materials are numerous and wide, regulating the administrative management, the technical requirements for reuse, the environmental and health and safety. Specific in-country regulations can vary significantly. Nowadays there are some examples of practical applications, and technical standards are under revision in order to be adapted to this new sector.

The use of waste as aggregates requires a complete removal of additives, as technical requirements adopt clean materials that will be mixed for concrete preparation. This context reflects the complex chemistry of cement reactions, where other substances can affect the short and long-term behaviour as far as hydration and durability are concerned. The use as material for embankments involves compaction requirements, shear strength and bearing capacity (e.g. rockfall defence). Use of additives can modify the behaviour of the muck in terms of stickiness, plasticity, abrasiveness, consistency, water conductibility and friction parameters. In the case of land reclamation, mining reclamation (Oggeri et al., 2019) and filling, the mechanical performances are less challenging, but a full assessment of chemical properties is needed for avoiding production of new leachate and diffusion of minor contaminants. Other uses should be studied case by case.

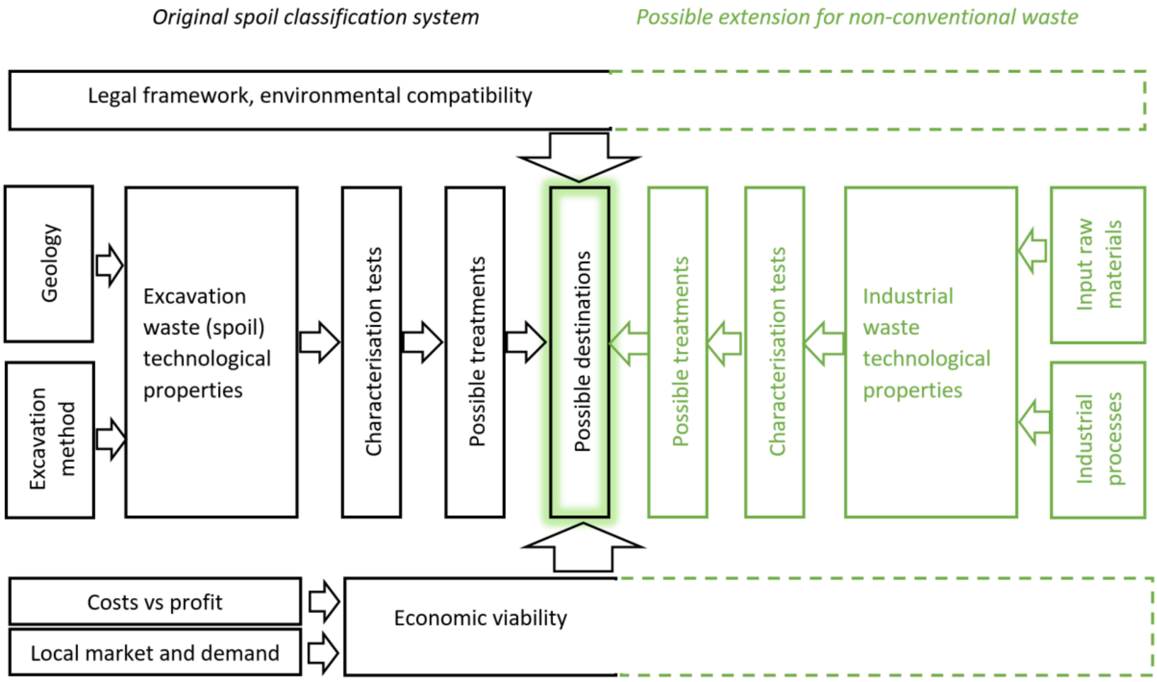

Figure 2. Diagram of the proposed classification and its possible extension on non-conventional waste.

Particular interest in the recycling of industrial waste lies in the development of low-carbon building materials, in response to the growing concern about CO_2 emissions of fired bricks, steel, Portland cement-based concrete. Alkali activated binders (also referred to as “geopolymers”) have emerged as a novel material with a promising potential to replace Portland cement. These binders consist of a class of inorganic polymer formed mainly by the reaction between alkaline chemicals (activators) and an aluminosilicate source (precursors). Precursor materials for this reaction can be sourced in waste streams from different industrial sectors. Fly ash, slag, ceramic, mining, and paper sludge waste have been successfully used as precursors for alkali activation. However, as discussed in Vinai et al. (2015), the suitability of these materials in developing the polymerisation reaction must be assessed through a detailed chemical and physical characterisation ensuring the availability of required chemical species in the appropriate quantity and physical state. Grain size distribution and specific surface area, the shape of the material grains, and the dissolution rate in alkaline environment are also key parameters to assess. Recent works also demonstrated the possibility of using waste stream such as glass waste for the production of low-carbon sodium silicate as binder activator (Vinai and Soutsos, 2018).

Conclusions

The growing amount of waste or non-productive materials arising from civil or mining excavations (debris, burden, spoils, mud) and from industry (mud, sludge, cuttings, sands, slag, ashes) is claiming for the reuse, rational and planned, even if partial. A field of interest is the possible reuse of muck from tunnelling and of overburden from quarries. The first step for successfully engage in significant recover of these materials is the availability of a robust classification system that enables to determine the proper technical and chemical path to address a convenient and suitable reuse. In a similar way, efforts have been done to look for applications, even if marginal, of non-conventional materials, originated in different, new and unpredictable ways. The assessment of the behaviour of these materials is required, especially when these are used in specific applications, such as for the creation of drainage layers, for covering of dumps, for rehabilitation and reclamation of old or abandoned excavation sites, for subgrade in road embankments.

Sampling methods, testing equipment and procedures, as well as geotechnical and physical characterisation are the three main aspects that need a special care when investigating these materials, because their real scale properties (that is when working on site) and short- and long- term behaviour can show significant variations with respect to traditional raw material. The process for improving the quality of these materials should be simple, inexpensive and requiring simple plants.

Finally, the technological and economic sustainability of these processes should be accompanied by a real commitment from all the involved stakeholders, from policymakers to industrial actors, in exploring and fostering these recycling options, otherwise it will remain a mere and marginal activity without real impact on economy, society and environment.

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