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REUSE OF EXCAVATED SOILS AND ROCKS IN NEW PRODUCTION CYCLES AS RAW EARTH BRICKS

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ABSTRACT: The construction of a tunnel, independently of the excavation technique, generates large quantities of excavated soils and rocks that are all too often considered and processed as waste, consequently generating costs related to transportation and disposal that generally sum up to about 30% of the total costs of the project, and also causing considerable CO_2 emissions. Webuild and GEEG have launched a research project, Wecycle, aimed at developing an integrated management system for excavated soils. The research activity involves the analysis of numerous real tunnelling projects, in Italy and abroad, and of a relevant number of different reuse modes, from the most common, as the morphological re-profiling, to more innovative uses with high added value. In this paper only one of the investigated reuse methods is described: the production of raw earth bricks using excavated soil. Cubic samples were made using different mix designs and their unconfined compressive strength was tested, evaluating the influence of the grain size distribution, of the strength class of the cement and of the addition of straw fibers.

1. INTRODUCTION

The management of excavation activities and the reuse of excavated soil and rocks are crucial aspects in the development of an underground construction project, which, if properly optimised, could lead to significant benefits in technical, economic and environmental terms. These aspects are completely in line with the concept of Circular Economy, based on the principle of "Reduce, Reuse and Recycle" (Ghisellini et al., 2018), that promotes the efficient and sustainable management of materials – excavated soils in the case at hand – to reduce waste production as much as possible.

The rapid increase of construction activities because of a growing population and urbanisation in many parts of the world generates a large amount of construction waste. These constitute about one third of the total waste generated in the European Union (EU) with an average reuse rate of just 46% (Poulikakos et al., 2017). The huge volumes of excavated soils and rocks, often with excellent chemical/physical/mechanical characteristics, also represent a potential that is still only partially explored. For a long time regarded as waste from a normative point of view, it is now possible to consider them as subproducts and to reintroduce them into production cycles or reuse them in development projects.

Currently, the ways in which excavated soil and rock are reused are often limited to applications such as filling of disused quarries or morphological reprofiling, which in any case often entail significant transportation and disposal costs. The increasing desire and need of reusing soils and rocks from excavation (Magnusson et al., 2015), often runs up against several complexities and constraints that greatly limit actual reuse (Simion et al., 2013). To overcome these limitations and unlock the real potential for reuse of these non-renewable natural resources, Webuild and GEEG developed the Wecycle project.

The project aims to explore innovative excavated soil and rock reuse solutions, some of which have already been sporadically tested with success, others experimented in the laboratory and others that are completely new, and to integrate them into a management system for the entire process that can become a useful design tool to provide the most virtuous and effective reuse solution for each individual project on the basis of technical, environmental, economic and logistical considerations (Sebastiani et al., 2023).

In this paper only one of the reuse methods studied and tested in the Wecycle project is described: the use of excavated soils and rocks to produce unfired earth bricks. The following illustrates the preparation of the cubic samples adopting different grain size distributions and the experimental tests performed to assess the unconfined compressive strength (UCS). The influence of the strength class of the cement and of the addition of straw fibers is also analysed.

2. EXPERIMENTAL ACTIVITY

2.1 Materials

To acquire data and information on how to manage excavated soil and rock belonging to different lithologies, the research activity in general was developed by using samples of soil and rock from 22 different geotechnical formations affected by the construction of tunnels and underground works in 8 major infrastructure projects in Italy and abroad.

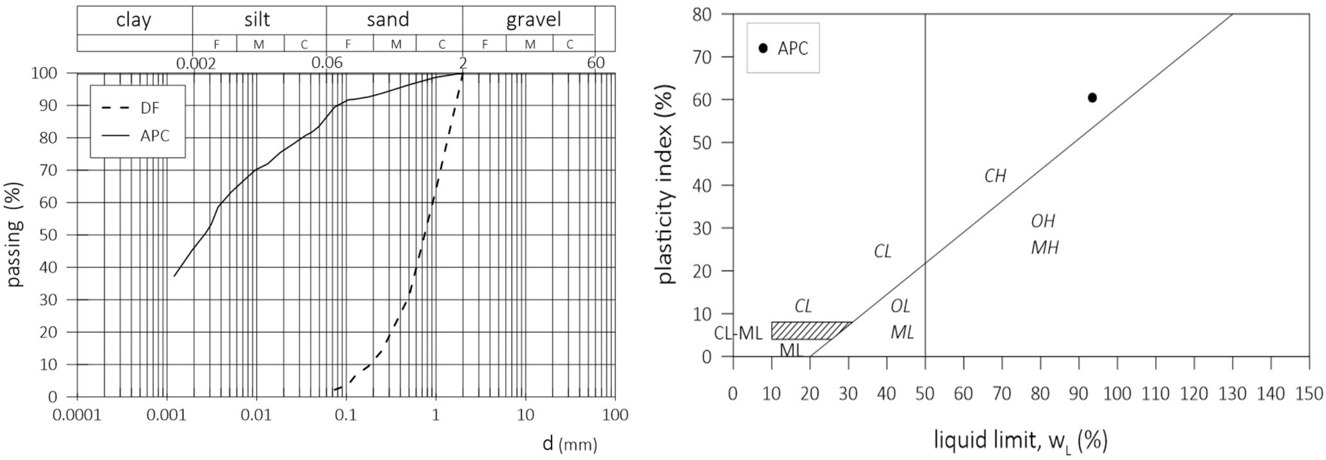
These formations were analysed in terms of:

- geotechnical characterisation (grain size distribution, Atterberg limits, specific weight of grains, ...);
- mineralogical composition by diffractometric analysis;
- chemical composition by fluorescence analysis;
- grain morphology (for sands and gravels) by process-imaging and electron microscopy;
- range of water content, void index (sands/gravels) and texture (clays/loams).

The characteristics obtained were used in the selection of the formations to be treated for making raw earth bricks. The latter, generally consist of sand, clay, and water; if it is needed to bring water-repellent properties to the brick, parts of cement are often added. Already in the past, with the *Cycle Terre Project*, the feasibility and use of soils produced by drilling for GPE (Gran Paris Express) in the production of raw earth bricks was evaluated.

A sandy formation and a silt/clay formation, respectively Df (fluvioglacial deposits) from the high-capacity railway extending from Verona to the Basis Brenner Tunnel (Fortezza Ponte Gardena site), and APC (Calaggio polychrome shales) from the Naples-Bari high-speed railway (Hirpinia/Orsara site), were selected for this study.

The soil classification was performed following the relevant standards (AGI 1994 and ASTM D 4318). The grain size distribution curves reported in Figure 1a show that Df is a sand with traces of fine, while APC is a silt with clay and 12% of sand (the soils were previously sieved to diameters smaller than 2 mm). According to the Casagrande plasticity chart (Figure 1b) these fines are CH, with a liquid limit equal to 93% and a plastic limit equal to 33%, thus resulting in a plasticity index equal to 60%. Df is 40% quartz, while APC only 14% with 25% of illite / smectite . Concerning the chemical composition, both soils are mostly siliceous (69% and 50% respectively).



a) *b)*

Figure 1. a) grain size distribution; b) APC Casagrande plasticity chart.

2.2 Methods

The raw earth bricks were made in cubes of 4 cm sides using three different Df-APC ratios (40-60%, 50-50%, 60-40%). The water contents were set to 25%, which is the value that provides the mix with better workability and is also not far from the values recorded by the conditioned soils in TBMs.

The production of bricks followed these steps (Figure 2):

1. powders (Df, APC and cement) are mixed in relation to the chosen mix design without the addition of water.
2. water is added up to a water content of 25%;
3. the powders are mixed manually until the water is completely absorbed;
4. the prepared mixture is divided into three parts, which will be used in the making of three raw earth bricks;
5. for making a brick, the mixture is divided into 3 parts further. The first part is placed in the mold and then pressed using hand press, at this stage, to avoid the formation of preferential sliding surfaces, cuts are made

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on the surface where the second part of the mixture is then placed;

6. to standardize the process, the first and second layers are pressed for 2 minutes and the third for 5 minutes,
7. bricks are cured under controlled conditions (humidity above 95% and temperature of 25± 2°C) and present a porosity index around 0.42;
8. unconfined compressive strength tests were performed at 7 to 14 and 28 days of curing.

a) *b)* *c)*

Figure 2. a) press; b) molds; c) raw earth bricks.

The main goal of the study was to evaluate the mechanical characteristics of the raw earth bricks, namely the UCS at this stage. As mentioned above, the tests involved several mix designs (Df/APC ratios). Further, the influence of the cement type (32.5R, 42.5R a 52.5R class II) and dosage (3, 5, 7.5, 10, 12.5%) was investigated. Finally, the effects of the addition of straw fibers (2.5, 5, 10%) to the mix were assessed.

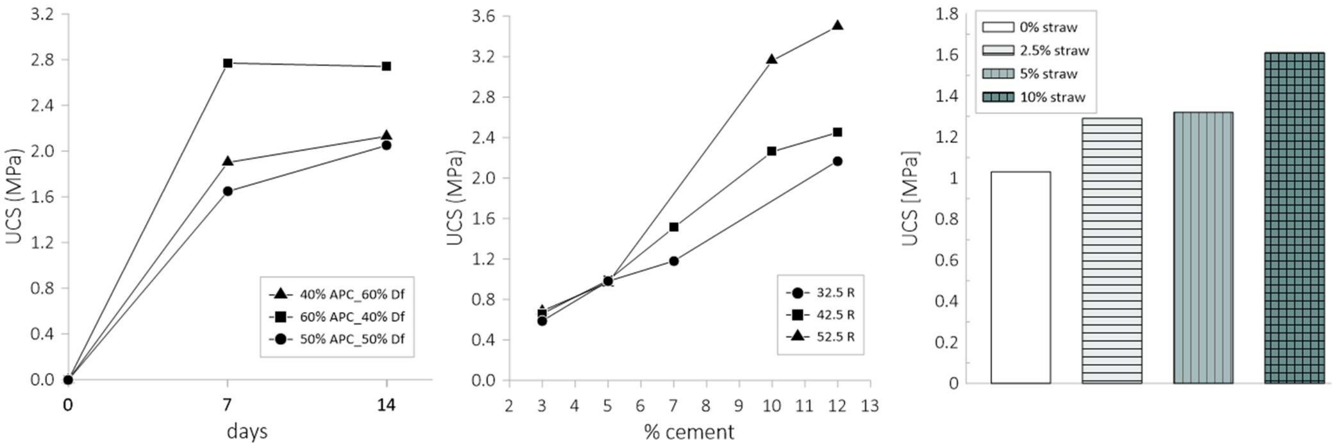
3. RESULTS

This paragraph reports the results of the experimentation. To ensure the reliability of the results, all tests were carried out in triplets (the values reported herein are the averages). In order to isolate and further investigate the influence of the parameters studied, it was decided to keep certain parameters constant at each stage.

The first phase (Figure 3a), involved the investigation and influence of the percentage of Df and APC on the strengths, while cement dosages and cement class were kept constant (class 52.5R, dosage 8%)The sample with 60% APC and 40% Df shows the best mechanical properties; its UCS is roughly 40% higher than the other samples at 14 days (2.8 MPa against 2 MPa). Samples made with a lower percentage of APC showed smaller unconfined compressive strength and also a slightly slower increase during time. The 28 day maturation results were not available due to problems in the laboratory, but we can imagine and predict a modest increase in resistances compared to those obtained from 14 day samples.

The second phase (Figure 3b) reports the influence of the cement class and dosage used in the preparation of the bricks. All results were obtained on sample cured at 28 days, made with different cement dosages (3, 5, 7, 10, 12.5%) and at 3 different cement classes, keeping the proportions between APC and Df constant (50% - 50%). The samples prepared with the cement with class 32.5R exhibit compressive strength values of 2MPa, those with class 42.5R 2.4MPa, and sample with the 52.5R about 3.5MPa. At low cement dosages, the difference in classes seems to have a negligible effect.

In Figure 3c, the strength values obtained on 7-day cured samples were compared by varying the percentage of straw fibres contained in the mix design. A mix of 50% APC and 50% Df with 5% of cement class 42.5 was used. As the fibres increase, the characteristics exhibited increase; in fact, the test with 10% straw have compressive strength values of 1.6MPa, compared to 1.03 MPa of those without straw, increasing unconfined compressive strengths by approximately 60 %. As per the size of the fibers, they were defined in proportion to the size of the cubic specimens with a maximum length of 1 cm.



a) *b)* *c)*

Figure 3.UCS tests: a) influence of the mix design at 7-14 days of curing; b) influence of the cement class and dosage at 28 days of curing; c) influence of the straw fibers at 7 day of curing.

4. CONCLUSIONS

The experimental activity described in the paper provides some insights into the mechanical characteristics of raw earth bricks produced using excavated soil and rocks and therefore about their potential in a virtuous circular economy model. The main conclusions are reported below:

1. the mix with 60% APC and 40% Df exhibits the highest mechanical properties. The prevalence of clay in the mix design had a significant influence on the strength of the brick, making it consequently more suitable for construction uses;
2. increasing the strength class of the cement provides higher mechanical properties. Comparing the results obtained at 28 days between the mixes with cement type 32.5R and 52.5R, an increase of approximately 75% is observed with the dosage of 12.5% cement in design mix.
3. the inclusion of straw fibers in the production process brings significant benefits in terms of strength, stiffness and ductility. An increase of strength about 60% compared to specimens without fibres was recorded.

Evidently, several aspects of this broad topic can still be explored and need further investigation. In particular it would be useful to evaluate the variation of mechanical characteristics when varying, not the resistance class of the cement, but the type (I, II, III or IV). Other topics that should be addressed include durability and behaviour in contact with water or the evaluation of acoustic and thermal insulation characteristics.

Nonetheless, the results reported above suggest a concrete yet improvable way of reusing excavated soils and rocks, ultimately pursuing the development of a management system integrated into the circular economy framework.

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