

From the ornamental stone production chain to tunnelling: Marble sludge and gneiss powder in two-component grout applications in the view of a sustainable backfilling phase

*Original*

From the ornamental stone production chain to tunnelling: Marble sludge and gneiss powder in two-component grout applications in the view of a sustainable backfilling phase / Todaro, C., Cardu, M., Di Giovanni, A., Carigi, A., Saltarin, S., Berariu, R., Firouzei, Y., Peila, D.. - (2026), pp. 4561-4569. (ITA World Tunnel Congress 2026 Montreal (Can) 15-21 May 2026) [10.1201/9781042001064-558].

*Availability:*

This version is available at: 11583/3016355 since: 2026-10-06T10:01:26Z

*Publisher:*

CRC Press

*Published*

DOI:10.1201/9781042001064-558

*Terms of use:*

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

*Publisher copyright*

(Article begins on next page)

# From the ornamental stone production chain to tunnelling: Marble sludge and gneiss powder in two-component grout applications in the view of a sustainable backfilling phase

C. Todaro, M. Cardu, A. Di Giovanni, A. Carigi, S. Saltarin, R. Berariu, Y. Firouzei and D. Peila

*Department of Environment, Land and Infrastructure Engineering (DIATI), Politecnico di Torino, Turin, Italy*

**ABSTRACT:** Sustainability is becoming more and more important in engineering works, and the underground world is also involved. When shield machines are used, the backfilling phase plays a crucial role in lining stabilisation and surface settlement control, and it is commonly carried out using the two-component grout technology. This study presents the outcomes of extensive research carried out at Politecnico di Torino, aimed at enhancing the sustainability of the backfilling process using marble sludge and gneiss powder as alternative constituents for component A of the grout. The research was conducted in two phases. The first focused on identifying optimal mix designs and characterizing the grouts according to established standards from the scientific literature. The second involved testing grout samples produced using a specially developed injection prototype, designed to replicate the actual injection system of tunnel boring machines. The results underscore the environmental advantages of utilising these alternative materials and highlight the critical need for simulating the injection process with the injection prototype. Since these materials have never been tested before in this context, their behaviour within the backfilling system should be studied in deep and it is essential to validate the material performance through a rigorous mixing and injection simulation to ensure reliability and effectiveness of the results.

## 1 INTRODUCTION

In full-face mechanised tunnelling, an annular gap (annulus) is formed between the excavated medium and the precast lining extrados when shielded machines are used. This gap must be continuously filled during the advancement (backfilling phase) to guarantee the stability of the linings, to control surface subsidence and to improve the waterproofing of the system (Oreste et al., 2021; Grasso et al., 2023). Nowadays, the most used technology is the two-component grout, valued for its rapid gelation and hardening, which optimises the backfilling phase from an operational and technical point of view. Operationally, it offers efficiency due to direct pumping (no need for a booster station) and fast-setting characteristics.

As the name of the technology suggests, two components are needed. Component A is produced on-site using common materials such as cement, water, bentonite, and additives. Component B is a ready-to-use sodium silicate solution. Recent studies have explored alternative materials for Component A, such as fly ash, slag, and industrial waste to reduce the dosage of cement and globally the carbon footprint of the two-component grout (Schulte-Schrepping, R. Breitenbücher, 2019; André et al., 2022). In view of making the tunnelling construction more sustainable and specifically the backfilling process, this study continued the research proposed in recent years from the Politecnico di Torino based on the use of marble sludge and gneiss powder in the two-component grout technology. Debris, obtained from the cutting process of ornamental stone, are used as replacements, aiming to reduce cement usage. The new mixtures showed environmental benefits compared to standard grout.

Considering that the debris addition to the standard ingredients of the two-component grout has never been tested at the real scale, a specific injection prototype was designed and built to simulate the real injection process at the laboratory scale. This new part of the study was designed to identify specific limitations that are difficult to detect using the standard study procedure.

The study is hence based on two different procedures for the two-component grout production:

- Procedure 1 (P1) – component A production phase and casting phase, according to Todaro et al. (2019) and Todaro et al. (2020), also called “standard approach”;
- Procedure 2 (P2) – component A and casting phase carried out by using a laboratory-scale injector.

P1 was used for the technical and sustainable assessment of the mix designs, while P2 was used to validate the outcomes of the previous step at a more realistic scale.

In the paper, the acronym 2CG will be used for two-component grout.

2 THE USE OF DEBRIS FROM THE ORNAMENTAL STONE PRODUCTION IN TUNNELLING

The ultimate goal of achieving Net Zero Carbon by 2050 represents one of humanity’s most significant challenges. The decarbonization effort must encompass all sectors of human activity, production systems, and infrastructures. The use of underground space offers a promising solution for minimizing the carbon footprint in urban areas (Wei et al., 2024; Bobylev et al., 2023). However, tunnelling is a highly complex infrastructure process that requires not only a comprehensive and integrated approach to sustainability (Eckbauer et al., 2014) but also a focused evaluation of the construction stages—particularly regarding the selection of materials and technologies.

In this paper, debris obtained from the ornamental stone cutting process have been used as row ingredient for the 2CG production (Figure 1). In the Italian context, marble and gneiss debris have been used, as quarries of these rocks are widely distributed across the country.

Against this background, incorporating stone debris into 2CG offers substantial environmental benefits. On one hand, it reduces the use of specific components in the standard grout mix by partially replacing them with recycled materials; on the other hand, it decreases the demand for landfill space by reusing materials that would otherwise be discarded.



Figure 1. Marble sludge used in the production of 2CG.

### 3 MATERIALS AND TESTING METHOD

#### 3.1 *Used materials*

The 2CG studied in this research was produced using high-strength cement CEM I 52.5 R provided by Buzzi Unicem. Retarding/fluidifying agent (Mapequick CBS1), Accelerator (Mapequick CBS3) and bentonite (Mapebent CBS4) have been supplied by Mapei. As for debris, the marble powder was collected in a quarry in Tuscany, while the gneiss powder was provided by a quarry in Val D'Ossola (North-West of Italy). The marble was collected in a dry state, as the cutting operations carried out at the exploitation site were performed using the chain cutting machine without lubricants. The gneiss powder was wet, as obtained from cutting operations carried out with the diamond wire saw. The grain size distributions are reported in Figure 2. The two different curves related to marble refer to the original material and the crushed one. The need for a finer marble sludge will be explained in the following paragraphs. The X-Ray-Diffraction Analysis (XRD) results indicated that the marble sludge consisted purely of calcium carbonate, while the gneiss powder mainly contained quartz, feldspars, and mica.

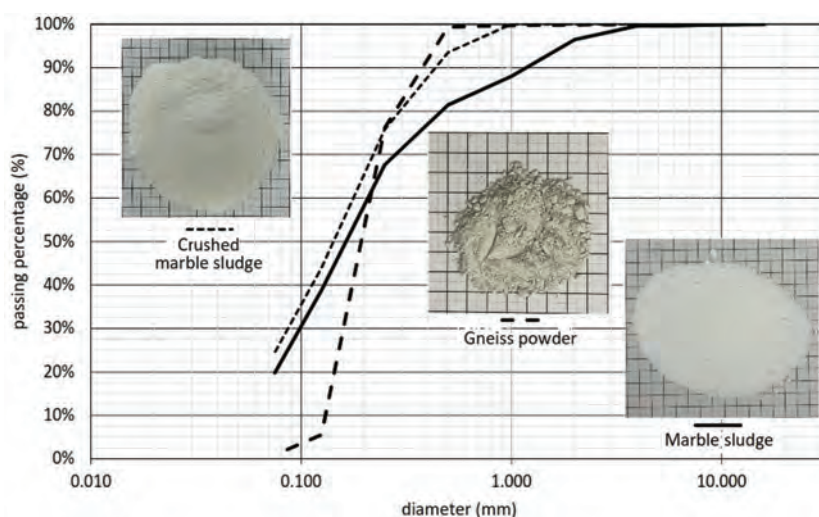


Figure 2. Grain size distributions of the 3 materials used: crushed marble sludge, gneiss powder and marble sludge. The background reference unit is 1 cm.

#### 3.2 *Mix designs*

Starting from the reference mix design (hereinafter mix R) previously studied in other authors' papers, several tests have been carried out to reduce the dosage of cement while increasing as much as possible the content of debris. This approach was chosen to reduce the amount of binder (whose production chain has a significant environmental impact) by replacing it with debris that can act as aggregates.

From a whole dataset of more than 18 mix designs, results reported in previous research have been further optimised with a new mix design, namely "mix 4-Gneiss powder."

Hereinafter, to make reading easier, the mix designs are referred as Mix 3 and Mix 4 (Table 1).

Table 1. Reference 2CG mix-design, values expressed in kg per m<sup>3</sup> of grout.

| Ingredient                  | Mix R | Mix 3-Marble sludge | Mix 4-Gneiss powder |
|-----------------------------|-------|---------------------|---------------------|
| Cement                      | 230   | 180                 | 160                 |
| Bentonite                   | 30    | 30                  | 30                  |
| Debris                      | /     | 200                 | 250                 |
| Water                       | 853   | 795                 | 780                 |
| Retarding/fluidifying agent | 3.5   | 3.5                 | 6.0                 |
| Accelerator                 | 81    | 81                  | 81                  |

### 3.3 Testing methods

The two-component grout properties have been assessed on samples produced using procedures P1 and P2. Table 2 summarises the considered parameters, the testing timing, and the references used.

Todaro et al. (2019) and Todaro et al. (2020) provide detailed descriptions of the testing procedure.

Table 2. Testing methods used for the 2CG assessment.

| Material tested           | Parameter measured                                                               | Timing                | Reference                                                       |
|---------------------------|----------------------------------------------------------------------------------|-----------------------|-----------------------------------------------------------------|
| Comp. A                   | Unit weight (kg/L)                                                               | On the fresh grout    | ASTM D4380, 2020                                                |
| Comp. A                   | Bleeding (%)                                                                     | At 1,3 and 24 h       | UNI 11152-11, 2005                                              |
| Comp. A                   | Viscosity - Marsh funnel (s)                                                     | at 0, 24, 48 and 72 h | UNI 11152-13, 2005                                              |
| Component A + Component B | Gel time (s)                                                                     | On the fresh grout    | bucked pouring method (Todaro et al., 2019; André et al. 2022); |
| Hardened grout            | Surface Compression Strength (SCS) with penetrometer (MPa)                       | At 1 and 3 h          | Todaro et al. (2020)                                            |
| Hardened grout            | Uniaxial compressive strength (UCS) and tensile strength (T <sub>0</sub> ) (MPa) | 1, 7 and 24 days      | CEN (2016)                                                      |

## 4 THE STANDARD APPROACH

### 4.1 The Component A production and mixing phase according to P1

Component A was produced using the well-established procedure set-up at the Politecnico di Torino, namely using a laboratory mixer and an impeller. The phases of the procedure are reported in Table 3. More details pertaining to the equipment used are reported in Todaro et al. (2019).

The 2CG samples were produced manually, following the procedure described in Todaro et al. (2020). The correct amounts of Components A and B were previously measured in two separate buckets. Subsequently, Component A was poured into the container of Component B, and the resulting mix was continuously and quickly poured back and forth between the two buckets until

Table 3. Mixing procedure P1.

| Phases                                                  | Impeller rotation speed (rpm) | Duration (min) |
|---------------------------------------------------------|-------------------------------|----------------|
| Start – only water                                      | 800                           | /              |
| Bentonite addition and mixing phase                     | 2000                          | 7              |
| Debris addition and mixing phase                        | 2000                          | 15             |
| Cement addition and mixing phase                        | 2000                          | 3              |
| Retarder/fluidifying agent addition, mixing phase - End | 2000                          | 2              |

casting into the mould, just before gelation. The mould dimensions comply with CEN, 2016. The curing was carried out in the moulds for testing times of 1 and 3 hours, in water at a controlled temperature of  $23 \pm 2$  °C for a longer curing time.

#### 4.2 Results on samples produced according to P1

The results concerning sample prepared according to P1 are reported in Table 4.

Table 4. Obtained outcomes for Component A and the 2CG produced according to P1.

|                                | Mix R<br>(Todaro et al. 2024) | Mix 3<br>Marble sludge | Mix 4<br>Gneiss Powder |
|--------------------------------|-------------------------------|------------------------|------------------------|
| Unit weight (kg/L)             | 1.17                          | 1.24                   | 1.29                   |
| Flow time – fresh grout (s)    | 34.5                          | 38.5                   | 38.5                   |
| Flow time – 24 h (s)           | 41.0                          | 37.5                   | 40.0                   |
| Flow time – 48 h (s)           | 43.0                          | 37.5                   | 39.0                   |
| Flow time – 72 h (s)           | 51.0                          | 37.5                   | 38.5                   |
| Gel time (s)                   | 8.0                           | 12.0                   | 10.5                   |
| SCS – 1h (MPa)                 | 0.41                          | 0.31                   | 0.28                   |
| SCS – 3h (MPa)                 | 1.62                          | 0.98                   | 1.24                   |
| Bleeding – 1h (%)              | /                             | /                      | 0.00                   |
| Bleeding – 3h (%)              | $\approx 1.00$                | 1.04                   | 0.69                   |
| Bleeding – 24h (%)             | 2.09                          | 5.02                   | 3.29                   |
| T <sub>0</sub> – 1 day (MPa)   | /                             | 0.41                   | 0.38                   |
| T <sub>0</sub> – 7 days (MPa)  | /                             | 0.57                   | 0.49                   |
| T <sub>0</sub> – 28 days (MPa) | 0.37                          | 0.59                   | 0.61                   |
| UCS – 1 day (MPa)              | 1.04                          | 1.00                   | 0.94                   |
| UCS – 7 days (MPa)             | /                             | 1.29                   | 1.24                   |
| UCS – 28 days (MPa)            | 1.64                          | 1.46                   | 1.61                   |

## 5 THE INJECTOR PROTOTYPE

When a new material is proposed for the market, such as, in our case, the 2CG prepared using debris, a further step of the study, carried out at a scale more representative of real construction site conditions, is strongly recommended.

In this study's second phase, an expressly developed injection prototype designed to replicate the injection system of tunnel boring machines was developed and used.

### 5.1 The Component A production and mixing phase according to P2

A picture of the injection prototype is given in Figure 3. The turbomixer used for producing Component A was a Lorenzetto L150, a real turbomixer commonly employed on little construction sites. The mixer was connected to the storage tank of Component A (item 4 in Figure 3). The feeding line of Component A was activated through the turbomixer's pumping system. Once the storage tank was full, Component A was allowed to flow into the pressurization pipe. Similarly, Component B flowed from the storage tank (item 5 in Figure 3) to its corresponding pressurization pipe. The storage tanks were introduced for simulating the back-filling containers located on the TBM. Injection began once the pressurized pipes reached the wanted pressure (which could differ between components, if required). The valves were previously adjusted to ensure the prescribed ratio between Component A and Component B, according to the mix design. The molds used complied with CEN, 2016.

Table 5 reports the procedure for producing Component A. It results from a specific study carried out with the assistance of turbomixer technicians to replicate conditions comparable to those on

a construction site. A minimum of 30 L per batch was produced to ensure proper mixing of the components.

The details of the injection nozzle are reported in Figure 3, right. The pipe of Component A has a diameter of 21 mm, while the pipe of Component B has a diameter of 10.5 mm. Two

Table 5. Mixing procedure P2.

| Phases                                                                   | Engine rotation speed (Hz) and<br>Impeller rotation speed (rpm) | Duration<br>(min) |
|--------------------------------------------------------------------------|-----------------------------------------------------------------|-------------------|
| Start – only water                                                       | 25 - 750                                                        | /                 |
| Bentonite addition and mixing phase                                      | 50 - 1500                                                       | 3                 |
| Debris addition and cement addition at the same<br>time and mixing phase | 50 - 1500                                                       | 2                 |
| Retarder/fluidifying agent addition, mixing phase -<br>End               | 50 - 1500                                                       | 1                 |

non-return valves are installed before the T-connection (diameter of 21 mm). The output nozzle has a dimeter of 13.7 mm.

Using the injection prototype was crucial: after the first preliminary tests, it became clear that the marble sludge’s grain size was unsuitable for injection. After casting approximately 10 L of the 2CG grout, the nozzle became choked with marble debris. The first solution adopted to overcome the problem was to increase the injection pressure of the components, but this attempt proved unsuccessful. It was consequently decided to crush the marble sludge, obtaining the “crushed marble sludge” of Figure 3, a material with a maximum particle size lower than 0.5 mm. No issues were encountered when using the gneiss powder.

The results presented in the following sections are consequently referred to the gneiss powder and the crushed marble sludge.



Figure 3. Injection prototype used for the mixing procedure P2. On the left: 1. Mixer control panel for Comp.A production; 2. Mixer + pumping system; 3. Comp.A pumping pipe; 4. Comp.A storage tank; 5. Comp.B storage tank; 6. Comp.A delivery pipe to the pressurization system; 7. Comp.A pressurization pipe; 8. Comp.B pressurization pipe; 9. Compressed air pressurization system; 10. Comp.A delivery pipe to the nozzle; 11. Comp.B delivery pipe to the nozzle; 12. Mixing and injection nozzle. On the right, a detail of the injection nozzle: A. Comp.B feeding line; B. Comp.A feeding line; C: nozzle exit.

## 5.2 Results on samples produced according to P2

Component A produced with the turbomixer and the 2CG samples produced according to P2 were tested. The results were used for comparison with the 2CG obtained using the standard procedure (P1). Table 6 summarises the outcomes. It is important to note that the strength comparison was carried out only in the short-term.

Table 6. Obtained outcomes pertaining to Component A and 2CG produced according to P2.

|                                | Mix 3 – Marble<br>sludge – P1 | Mix 3 – Marble<br>sludge – P2 | Mix 4 - Gneiss<br>Powder – P1 | Mix 4 - Gneiss<br>Powder – P2 |
|--------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Unit weight (kg/L)             | 1.235                         | 1.200                         | 1.29                          | 1.26                          |
| Flow time – fresh<br>grout (s) | 38.5                          | 32                            | 38.5                          | 33                            |
| Flow time – 24<br>h (s)        | 37.5                          | 32                            | 40                            | 36                            |
| Flow time – 48<br>h (s)        | 37.5                          | 32.5                          | 39                            | 35.5                          |
| Flow time – 72<br>h (s)        | 37.5                          | 32                            | 38.5                          | 37                            |
| Gel time (s)                   | 12                            | 13                            | 10.5                          | 12                            |
| SCS – 1h (MPa)                 | 0.31                          | 0.31                          | 0.28                          | 0.34                          |
| SCS – 3h (MPa)                 | 0.98                          | 1.14                          | 1.24                          | 1.14                          |
| Bleeding – 1h (%)              | 0.00                          | 0.72                          | 0.00                          | 0.52                          |
| Bleeding – 3h (%)              | 1.04                          | 1.43                          | 0.69                          | 0.87                          |
| Bleeding – 24h (%)             | 5.02                          | 7.16                          | 3.29                          | 6.23                          |

## 6 DISCUSSION

The first part of this paragraph focuses on the technical comparison between the 2CG prepared according to procedure P1, with reference to Mix R, Mix 3-marble sludge and Mix 4-gneiss powder. For this analysis, the marble sludge used was the original one (not crushed).

Considering the unit weight, the reference value of 1.17 kg/L increased by about 5% and more than 10% for Mix 3 and Mix 4, respectively. This effect is probably related to partially replacing water (unit weight of 1 kg/L) with other heavier materials. Considering the flow time, the fresh components A are very similar at  $t_0$  (immediately after production), even if the innovative products exhibit slightly smaller viscosity. Noteworthy that for the innovative Components A, the flow times remain quite constant till 72h (37-39”), while for mix R, an increase is clearly appreciable (from 34.5” at  $t_0$  till 51” after 72h). The preservation of a lower (and stable) viscosity of the innovative mix could be due to the lower cement dosage used. The gel time of the innovative mixes was higher than the reference value of 4 and 2.5” for Mix 3 and 4, respectively. This longer gel time could be attributed to the lower cement dosage in the new mixes compared to Mix R.

Regarding physical stability, the innovative mixes exhibited no bleeding after 1 h of curing and values close to 1% after 3 h, similar to mix R; however, after 24 h, the stability of the innovative Component A decreased, and the bleeding values reached approximately 5% and over 3 % for Mix 3 and 4, respectively.

Regarding early-age strength, the surface compressive strength (SCS) measured after just 1 hour of curing was slightly lower for the innovative mixes. Specifically, Mix 3 and Mix 4 showed reductions of approximately 24% and 32%, respectively, compared to Mix R. The reduction was confirmed also after 3 hours of curing: Mix 3 exhibited a strength reduction of around 40% relative to Mix R, while the reduction for Mix 4 was about 23%.

Regarding long-term strength, Mix 3 and Mix 4 exhibited comparable results, reaching approximately 0.4 MPa after one day and around 0.5 MPa after seven days of curing.

A meaningful comparison with Mix R could be made after 28 days, when Mix 3 and Mix 4 showed substantial gains in tensile strength, about 60% and 65% higher, respectively. This significant improvement in long-term tensile performance is likely due to the inclusion of debris in the mixtures. As for the UCS, all mixtures exhibited similar values after one day of curing, around 1 MPa. After 28 days, Mix 4 exhibited the same UCS as Mix R (about 1.6 MPa), while Mix 3 showed a slight decrease in strength of approximately 10% compared to mix R. Although UCS data for Mix R at the 7-day mark were unavailable, Mix 3 exhibited a value close to 1.3 MPa, slightly higher than that of mix 4. Considering the overall results obtained, Mix 3 and 4 are suitable for standard 2CG applications.

Taking into account the outcomes obtained with the injection prototype, a difference between Component A prepared according to P1 and P2 can be observed, regardless of the mix design.

Component A prepared using the turbomixer was slightly lighter, with a reduction in unit weight of 3% for Mix 3 and 2.3% for Mix 4. The different mixing procedure also affected the activation of the bentonite, making it less effective. This conclusion is based on the following observations:

- fluidity: values were found to be 13–17% lower for Mix 3 and 4–14% lower for Mix 4 (over a time span of 0–72 h) compared to the same mixes prepared using procedure P1;
- bleeding: non-zero values were recorded after 1 h of curing (whereas for P1 the values were 0%). After 3 h, the mixes prepared with procedure P2 showed an increase in bleeding of 38% and 26% for Mix 3 and Mix 4, respectively. After 24 h, higher bleeding values were confirmed, reaching approximately 7 % for Mix 3 and 6% for Mix 4. These percentages are very close to the commonly accepted threshold (7-8%).

The gel time appeared to be only marginally affected by the change in procedure.

Regarding SCS, after 1 h of curing, the same numerical result (0.31 MPa) was obtained for Mix 3, regardless of the procedure used. For mix 4, a slightly higher performance (about 20% more) was recorded for the sample produced with P2. After 3 h, results were very similar, although a slight negative fluctuation (a reduction of about 15%) was observed for Mix 4 cast according to P2.

Considering the overall results obtained, even when using P2, Mix 3 and 4 can be regarded as suitable for standard 2CG applications.

## 7 CONCLUSIONS

This study represents a further chapter in the ongoing research started in 2022 at the Politecnico di Torino. Several two-component grout mix designs were tested with the aim of optimising the dosages of debris obtained from the cutting process of ornamental stone. Mix 3, prepared using marble sludge, and Mix 4, prepared with gneiss powder, proved to be the most technically suitable solutions. From a sustainability point of view, assuming a shield machine with a diameter of 10 m and a thrust length of 1.7 m, and taking Mix design R as a reference for comparison, it can be computed that for each thrust:

- over 500 kg and 700 kg of cement can be saved using Mix 3 and Mix 4 respectively;
- over 600 and 770 kg of water can be saved using Mix 3 and Mix 4 respectively;
- approximately 0.8 and 1 m<sup>3</sup> of landfill space can be saved using Mix 3 or Mix 4.

Considering that cement is one of the most energy-intensive components used in the backfilling process, CO<sub>2</sub> emission could be reduced by over 400 kg per thrust when using Mix 3, and by more than 550 kg when using Mix 4.

The use of the injection prototype imposed a significant constraint on the preliminary testing phase: the marble sludge obtained from the chain cutting machine (see Figure 1) cannot be used directly for backfilling purposes, as its grain size distribution is too coarse. Therefore, a crushing process is required. For practical applications, this additional operation should be considered in the overall emission assessment, along with the transportation of debris from

quarries to tunnelling construction sites. Finally, it should be noted that a positive balance in terms of CO<sub>2</sub> emissions can only be achieved for specific construction sites, located near areas where debris is produced. The testing campaign is currently ongoing and is focused on a pilot project.

## ACKNOWLEDGMENTS

The authors thank Utt Mapei, Buzzi Unicem and Beltramo Fratelli for supporting this research. This publication is part the project NODES which has received funding from the MUR – M4C2 1.5 of PNRR funded by the European Union – NextGenerationEU (Grant agreement no. ECS00000036).

## REFERENCES

- André, L., Bacquié, C., Comin, G., Ploton, R., Achard, D., Frouin, L., Cyr, M., 2022. Improvement of two-component grouts by the use of ground granulated blast furnace slag. *Tunnelling and Underground Space Technologies*: 122, 104369. <https://doi.org/10.1016/j.tust.2022.104369>.
- ASTM D4380, 2020. Standard Test Method for Determining Density of Construction Slurries. American Society for Testing and Material International.
- Bobylev, N., Guo D., Benardos A. (2023). Urban underground space use in a climate neutral city. *Proceedings of the ITA WTC World Tunnel Congress 2023, May 12-18, Athens (EL)*: 9–13, DOI: 10.1201/9781003348030-2.
- CEN. 2016, Methods of testing cement - part 1: determination of strength. EN 196–1:2016. European Committee for Standardization, Bruxelles (B).
- Eckbauer, W., Romed I., Dietmar Z. 2014. Planning optimisation for the Brenner Base Tunnel considering both maintenance and sustainability. *Geomechanics and Tunnelling* 7: 601–609. <https://doi.org/10.1002/geot.201400030>.
- Oreste P., Sebastiani D., Spagnoli G., de Lillis A. Analysis of the behavior of the two-component grout around a tunnel segmental lining on the basis of experimental results and analytical approaches. (2021). *Transportation Geotechnics* 29, 100570, DOI: 10.1016/j.trgeo.2021.100570
- Grasso, P., Lavagno, A., Brino, G., et al. in: Bilotta, E., Casale, R., di Prisco, C.G., Miliziano, S., Peila, D., Pigorini, A., Pizzarotti, E.M., (Eds), *Handbook on Tunnels and Underground Works: Volume 2: Construction – Methods, Equipments, Tools and Materials*, CRC Press, Boca Raton, London, New York, 2023, Leiden, pp. 11–216. 10.1201/9781003306467-2.
- Schulte-Schrepping, C., & Breitenbücher, R. 2019. Two-component grouts with alkali-activated binders. In: *Proceedings of the ITA-AITES World Tunnel Congress 2019, Naples (IT), May 3–9*.
- Todaro, C., Bongiorno, M., Carigi, A., Martinelli, D. 2020. Short term strength behavior of two-component backfilling in shield tunneling: comparison between standard penetrometer test results and UCS. *Geingegneria Ambientale e Mineraria* 159(1): 33–40.
- Todaro, C., Carigi, A., Cardu, M., Peila, D. 2024. Marble sludge in two-component grout applications. In: *Proceedings of the ITA WTC World Tunnel Congress 2024, Tunnelling for a better life – WTC 2024, April 19-25, Shenzhen (CN)*: 842–847, DOI: 10.1201/9781003495505-114.
- Todaro, C., Peila, L., Luciani, A., Carigi, A., Martinelli, D., Boscaro, A. 2019. Two component backfilling in shield tunneling: laboratory procedure and results of a test campaign. In: *Proceedings of the ITA WTC World Tunnel Congress 2019, May 3–9, Naples (IT)*. DOI: 10.1201/9780429424441-340.
- UNI 11152-11, 2005. Sospensioni acquose per iniezioni a base di leganti idraulici - Caratteristiche e metodi di prova. Ente nazionale italiano di unificazione.
- UNI 11152-13, 2005. Sospensioni acquose per iniezioni a base di leganti idraulici - Caratteristiche e metodi di prova. Ente nazionale italiano di unificazione.
- Wei, L., Guo, D., Zha, J., Bobylev, N., Chen, Z., Huang, S. (2024). Estimation of the ecological carbon sink potential of using urban underground Space: A case study in Chengdu City, China. *Tunnelling and Underground Space Technology* 144,105533, <https://doi.org/10.1016/j.tust.2023.105533>.