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The washing-out resistance of the two-component grout: A laboratory test campaign

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ABSTRACT: The two-component grout is the backfilling technology more frequently used in tunnelling construction where shielded machines are adopted. Despite its intensive use, different aspects of the technology have not been deepened sufficiently, particularly concerning the role of the two-component grout in the waterproofing of the tunnel. In fact, despite in scientific literature the engagement of the two-component grout in the protection of assembled linings against the water inflows is often mentioned, no proofs of this ability are available. Furthermore, in case of presence of water, the freshly injected two-component grout may be washed out reducing its thickness and, consequently, its waterproofing capacity but also this aspect have never been investigated. In this work, the impact of water on the fresh two-component grout is studied in laboratory by using an innovative apparatus, expressly designed and realised for the purpose. A test procedure is introduced and preliminary obtained outcomes highlight the aptitude of the grout to exhibit the washing-out resistance.

1 INTRODUCTION

The two-component grout is currently the most popular technique for the backfilling, a crucial phase that occurs during the advancement of a shielded machine (Todaro et al. 2022a). Since the bored diameter is bigger than the diameter of the linings extrados (because of the action of the overcutting tools, the shield conicity, the shield thickness and the presence of the tail brushes), a gap is constantly created (Thewes & Budach, 2009). This gap must be continuously filled during the machine advancement. A right performed backfilling phase by means of the two-component grout permits to lock linings in the designed position quite instantaneously (the gel time has order of magnitude of seconds), prevents surface subsidence, distributes eventual punctual loads acting on the lining, bears the backup-load. If evidences coming from construction sites confirm all the above listed positive occurrences derived from the use of the two-component grout, the impact of water on this grout technology is a controversial issue. In the scientific literature, many authors stated that the two-component grout exhibits anti-wash-out properties (Guglielmetti et al. 2007, Reschke & Noppenberger, 2011, Pelizza et al. 2010, 2012, Peila et al. 2011, Dal Negro et al, 2014, 2017, Càmara, 2018) but, related to this topic, tests have never been designed or performed and neither any information from construction sites are available. The only well-structured research available in the literature was performed by Youn & Breitenbücher (2014), who studied the dewatering by using an expressly modified filter press; however, the tests were performed on a different kind of mono-component grout.

In order to fill this scientific gap, in the laboratory of Politecnico of Turin, a specific test campaign aimed to estimate if and with what effect water can interact with the two-component grout has been planned. Before to start with the test description, some reflections should be made on the injection system of the machine. Considering that the injection pressure is always higher than the front face pressure (Thewes, 2013), and considering that the front face pressure is computed taking into account also the groundwater pressure, it can be stated that the backfilling grout,

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during the injection, pushes the eventually present water and fills the annular void. Plainly, if the groundwater does not move, its presence is a favourable condition for the durability of the backfilling (Peila et al. 2011). But what happens if the water moves? It could be that the movement of groundwater disturb the gelling and curing of the grout and modifies its characteristics in an undesired way.

The idea was to design a specific apparatus to be able to apply a constant water action, in terms of water velocity, on samples of two-component grout. Only short curing times were investigated. After a certain time of flow, the samples were tested in order to check if the action of the water had washed out part of them.

2 MATERIALS AND TEST PREOCEDURE

A specific apparatus and two-component grout samples were realised for the purpose. The basic idea was to apply a flow of water channelled inside holes expressly created in the specimens of two-component grout. The water level is fixed (constant hydraulic head), and it flowed through the hole for a scheduled time. After the flow phase, the diameters were tested in order to verify if the water had washed out part of the grout, enlarging the original hole. The diameter assessment was performed indirectly.

Two different test phases can be distinguished:

- the flow phase;
- the sample testing phase.

2.1 *Apparatus*

A plexiglass container was used as sample holder.

The container was designed to contain a number of specimens to be tested between 1 and 8. For each sample slot, the container was drilled with a hole of 10 mm (8 holes were realised in a quincunx pattern). Each sample, with height (h), was located centrally in the designed positions (coaxially to the hole of the sample slot) surmounted by a water table (Δh). Samples were centrally pre-drilled (with diameter of the hole ϕ) and linked with a watertight paste at the container bottom before starting the test. A pump feeds the water flow on the container and a drain guarantees a fixed water head (Δh) on the samples surface. The inlet water flow that feeds the system does not act directly on the samples: a plexiglass slab (slightly smaller than the container, 10 mm in length and depth), raised on 4 screws, protects samples from the potential generated turbulence, acting as a water diffuser. Under the sample holder, a water storage tank holds the flowed water

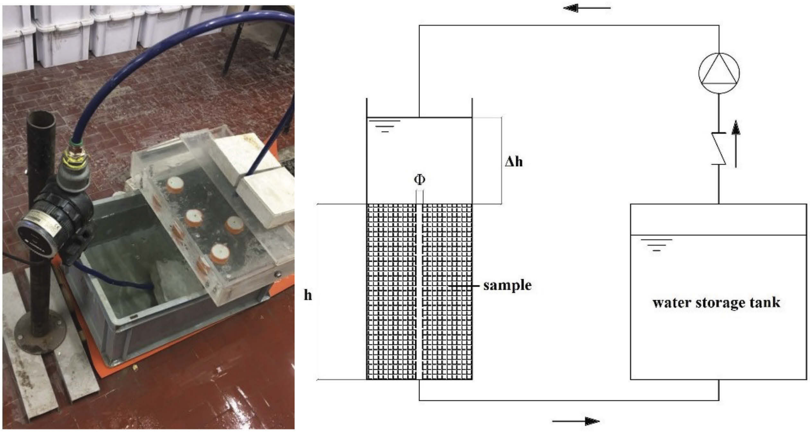

Figure 1. Photo of the developed device (left) and schematic drawing of the plant (right).

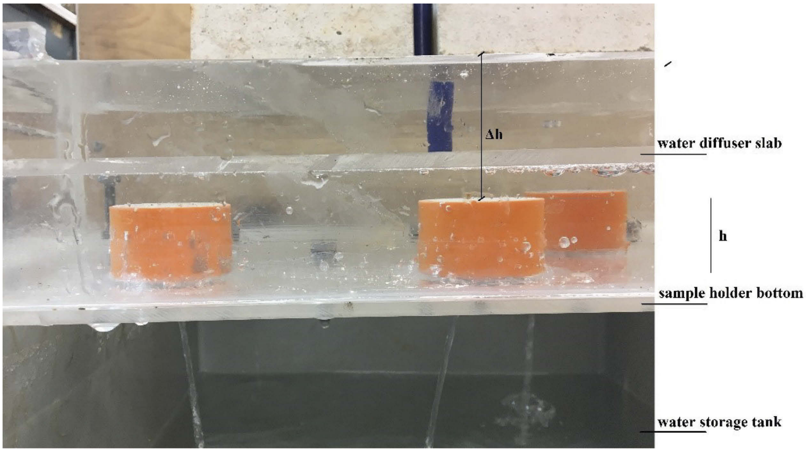

Figure 2. Photo of details of the designed apparatus.

that has crossed the samples, running in their inner holes. The head was kept constant through the realization of a spillway.

Figure 1 depicts a photo of the developed device (left) and a schematic drawing of the system (right). In Figure 2, a photo taken from a frontal point of view gives a better depiction of the details of the designed apparatus.

2.2 *Sample manufacturing*

The component A for the two-component grout was produced according to the procedure described in Todaro et al. (2019). The mix design used was the same of previous research (Todaro et al. 2020a, Todaro et al. 2022b) and briefly hereinafter summarised: cement: 230; water: 853; bentonite: 30; regarding fluidifying agent: 3.5; accelerator: 81. All reported dosages are expressed in kg/m^3. Concerning the casting and the curing modality, the procedure described in Todaro et al. (2020b) was followed with the exception of the sample shape that is cylindrical in this case. The sample production was the most sensitive phase of the procedure. Since the test was designed to assess the two-component grout's wash-out resistance at short curing times, there was plainly a need to handle samples that were not yet completely hardened.

The moulds were fashioned from a commercial plastic tube. Each sample was characterised by an inner hole, located in the centre. The geometrical dimensions of the sample are reported in Table 1.

Table 1. Geometrical dimensions of produced samples.

Dimension	Value
Diameter (mm)	43.7
Height (mm)	30.2
Inner hole diameter ϕ (mm)	2.7
Inner hole area (mm2)	5.72

Due to the weakness of the material that was being tested, it was impossible to drill the samples after casting. Therefore, it was planned to cast the sample foreseeing a cylindrical solid in the centre. Common iron spikes were used for this purpose, with the only requirement being a suitable diameter, a perfectly smooth lateral surface and a length higher than the sample height. A polystyrene support was shaped in order to hold the sample moulds on the one hand, and to fix the iron spikes steadily on the other (Figure 3).

Figure 3. Polystyrene support used for the samples production.

The verticality of the spikes was accurately measured using a spirit level. The spikes' heads were carefully covered with a plastic layer to prevent grout leakage (before gelation, the two-component grout is still fluid and leakages can potentially lead to an incomplete mould filling). Before long, a thin layer of oil was painted on the spikes, in order to simplify their removal just before starting the test. After the preparation of the polystyrene support as described, the moulds were glued centrally with respect to the spikes. After the glue had set (not more than 15 minutes), samples were cast and after just one minute the spikes were pulled out slightly for a distance that allowed perfect levelling of the cast surface using a spatula. About 15 minutes after casting, the spikes were gently completely removed. The samples, still held in their moulds (making it possible to handle them without damage), were gently removed and located in the plexiglass sample holder slots, taking care to ensure the correspondence among the samples holes and the bigger ones of the slots (each sample hole must be concentrically aligned with the hole of the container slot). Before long, the moulds were immediately glued on the bottom of the container (a quick-setting silicone was used for this purpose) and the samples were covered with a plastic layer on their free surface (the casting surface of the samples), in order to prevent dehydration during the curing time.

2.3 *Flow phase: Testing procedure and parameters*

After the scheduled curing time, the samples were uncovered (only the plastic layer of the casting surface was removed) and the pump was switched on. The samples were tested without demoulding.

All tests were performed according to the following testing parameters:

- $\Delta h = 48.4$ mm
- $v_b \simeq 1.2\,\mathrm{m/s}$

where Δh is the height of the water table applied on the samples' top surface and v_b is the water velocity on the bottom of the samples.

The decision to calibrate the apparatus according to this value of water speed was as a compromise between the maximisation of the potential wash-out phenomenon and the choice of velocity values comparable to a real hydraulic conductivity. It was decided to simulate the test in a gravel context, simulating a very high value of hydraulic conductivity and high value of groundwater velocity.

2.4 *Sample testing phase: Testing procedure*

The sample testing phase occurred only after the flow phase. The samples (still held in moulds) were removed from the sample holder and put in another tank, under water, in order to prevent dehydration.

Assessment of the hole variations was performed indirectly, as the hole dimensions were too small to estimate using a calliper. Furthermore, it was not guaranteed that the hole diameter variation was constant along the sample height (the hole outer diameter measured on the samples surfaces was frequently very large due to the geometrical concentration of the flow action and not consistent with the real inner measurement).

Consequently, the Marsh cone was considered a suitable device for the purpose, being well established and known to engineers involved in tunnelling backfilling.

The sample testing phase procedure is described in the following. Apart from the Marsh cone and its specific container, a gasket and a support able to bear the sample were required, leaving the sample hole free and centred on the tank positioned below. Concerning the gasket, its dimensions must be able to perfectly seal the tail of the cone with the sample surface, avoiding leakage. It is strictly discouraged to use rigid gasket models. Soft ones can warp and change shape as a function of the sample surface (which, despite all precautions, will never be perfectly smooth).

Figure 4. Photo of the arrangement for the sample testing phase.

Previously, the sample had been positioned on the support and the gasket had been positioned concentrically with the sample hole. Initially, the cone was manually pressured on the gasket. Particular care had to be taken in checking that the system composed of the sample, the gasket, and the cone nozzle was perfectly aligned (Figure 4). After that, the lower hole of the sample was closed with one finger by the same operator who was managing the cone, while a second operator had to fill the cone with water up to the cone notch. Before long, the time count started when the cover from the hole was removed. According to the Marsh cone procedure (UNI 11152, paragraph 13), the time count was stopped when a level of 1 litre was reached in the container.

At least three different assessments had to be performed on each testing sample. Finally, the average time “Marsh Cone Average Time” was compared with a “Marsh Cone Reference Time”. The reference time was obtained by testing different samples (cured 28 days) realised with a hole that was expressly uniform in diameter and perfectly smooth, simulating the original hole of samples before the action of the water flow.

3 RESULTS

In the following, preliminary outcomes are presented. Table 2 reports data related to the tests performed on samples cured for 3–3.5 hours and then treated with a flow phase of 28 days.

It was decided to start from the most investigated curing time, according to the recent work available in scientific literature, i.e. the short curing time.

Table 2. Outcomes pertaining to the preliminary test campaign.

Assessment	Values
Curing time (h)	3 - 3.5
Flow phase (days)	28
Marsh cone reference time (s)	85.3
Marsh cone average time (s)	78.7
Δ (s)	6.7
Δ (%)	8

4 DISCUSSION

The outcomes highlighted a slight reduction of the flow time, equal to 8%. This reduction is directly correlated with the increase of the hole diameter. It should be underlined that the new hole, bored for the water flow, was purportedly not constant along all the sample depth. Unfortunately, in the absence of other comparison data it is not possible to comment decisively on the obtained value of 8%. However, it can be stated that the studied curing time is considered a “short curing time” and furthermore that $v_b \simeq 1.2$ m/s is a very high velocity value, which rarely occurs in tunnelling work beneath the ground water.

However, according to the theory that was speculated, the erosion phenomenon due to the water flow is concentrated in the first hours of the flow phase. According to the fast growth of the two-component grout mechanical performances that occurs at short curing time (UCS, shear strength, Young’s Elastic Modulus) as reported in Todaro et al. (2020a), (2021), Oreste et al. (2021) it can be reasonably speculated that also the grout’s washing-out resistance increases with the curing time, and consequently that the water wear action decreases with time. The outer layer of the material is worn out in the first instance by the water flow, while with extension of the time, the action of the water flow has less impact. However, in order to prove this theory, further tests are required, varying parametrically the flow phase and the curing time of the material before the action of the water flow.

5 CONCLUSIONS

The two-component grout is nowadays the first choice of backfilling technology due to its indisputable advantages, both operative and technological. Despite its intensive use, no studies are available on the anti-wash-out properties of this material after the gelation, despite in scientific literature different authors reported its aptitude to resist against a water flow action.

In this paper, an innovative apparatus is described correlated by a simple testing procedure able to assess if and how a certain two-component grout, after a certain curing time, resist to the water flow action. Preliminary results put alight a good resistance of the grout against the water flow, tested after short curing times. Further investigations are suggested, by varying both the curing time and the mix design, since the proposed outcomes are strictly related to the studied case. Anyway, the provided procedure and the detailed information pertaining to the apparatus reported in this work want to be a useful instrument for quantitatively measure and compare the anti-wash-out properties of the two-component grout.

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