BACKFILLING FOR SEGMENTAL LININGS IN UNDERGROUND STRUCTURES

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Summary

For usual backfill grouts the major advantage is the huge experience of using grout mixes whose compositions and proportions are well known and also well documented from numerous tests and observations. However, it is not possible to ensure the correct backfilling (without gaps) or the appropriate pumping conditions as the general approach followed on standards (applicable mainly on lab) cannot ensure the fitness of the product functional properties. However, for assessing and controlling such type of mixes a set of "*actual*" indicators must be defined and also useful protocols for testing by using non destructive techniques have to be designed for its validation. This paper deals with the testing protocol undertaken to the production of a backfill grout that fulfils the required demands defined by the contractor and owner for each case of high performance backfill.

Keywords: Backfilling, high performance backfill, long last workability, fast setting time, flowability, filling ability, NDT

1 Introduction

There are many options for characterizing a backfill grout. The most popular indicator has been its price, probably because it was considered a no relevant material and it was not, in general (an exception is the deep tunnels with high and long lasting deformations [1]) a subject of interest amongst concrete researchers in the past. Its importance is still incipient as it is possible to deduce from the scarce literature and standards. This is the reason for trying to use in its composition almost each type of fine aggregate, blended cements (with also low environmental cost), as well as low cement amounts, high contents of active mineral admixtures as fly ash, and high w/c ratios if the surrounding conditions allow it because the compressive strength or durability are not some of the main indicators considered [2][3][4]. However, a good performance backfill grout is characterized by its *workability* (*pumpability* and *flow-ability -including filling ability-*) and *setting time* (especially with water presence in the surroundings), etc. For the contractor, the cost, the workability and the early-age properties are important, while the owner focuses more on cost and on the increasing concern on the environmental impact of construction industry.

The general option is a high water-cement ratio, providing generally a higher workability (fresh grout property) while the pumpability and flowability, that are specific indicators of workability for the case of backfill grout, could be affected in case segregation of the mix occurs (and a mix with high w/c ratio is prone to segregate or bleed also without pumping it). Therefore, the goal is to find a combination that satisfies the demands during casting/curing/service together with the environmental and price demands by defining appropriate indicators to evaluate the grout. It is accepted that the definition of *high-performance concrete* not necessarily refers to a high strength demand but to other performance characteristics. In a similar way, the definition of a performance or high performance backfill grout (PBG or HPBG) is from the authors' point of view: *a backfill grout that fulfils the required demands defined by the contractor and the owner for each case.*

It is a fact that a PBG (independently of its composition and proportions) must be adaptable to the actual requirements or target needs. Therefore, this general option gives greater freedom to the designer and a triggering effect on technological innovations while allowing easier integration of the sustainability issues. However, for assessing and controlling such type of mixes a set of "*actual*" indicators must be defined and also useful protocols for testing by using mainly non destructive techniques have to be designed for its validation. A few number of specific standards exist at present [2][3] and do not provide always a clear definition of some of the main parameters or if so they do not have always a method associated to asses the property or they are appropriate for lab rather than for on site.

It is the purpose of this paper to analyse some of the advantages that are obtained from the increased use of the performance based general approach to derive a simple and more accurate protocol applicable for mix design on lab but also for quality control on site. Consequently, the protocol should be capable of defining the main testing methods what EFNARC [3] considers crucial for having a good backfilling: "The grout ***should be pumpable*** without segregation or bleeding, ***irrespective of the distance or time involved***. It may need also ***to remain workable for an unspecified*** period (sometimes up to 24 hs) for long or difficult delivery schedules and ***may need to stiffen or set quickly*** to provide rapid support to (invert) segments, or to achieve an early strength to reduce subsidence or prevent water washout. Consider this the following indicators must be defined and assessed: pumpability, flowability, remaining workability, setting time, and strength evolution by using new or adapted standard methods that will be summarised on next chapters.

2 General protocol for designing HPBG

Based on the advantages and disadvantages of the existing backfill assessment a five step testing protocol has adopted for designing and evaluating of a PBGt based on the compliance of the above selected physical properties: pumpability, flowability, remaining workability, setting time, and strength evolution by using three main testing tools for measuring such properties (see fig. 1) as it is described below.

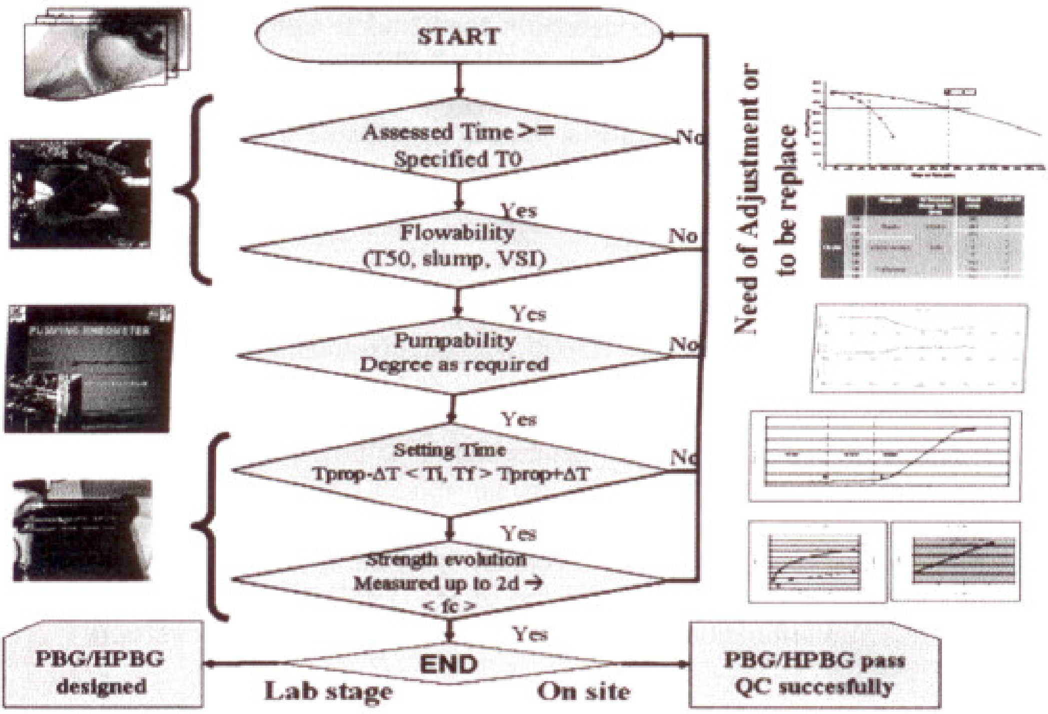

Fig. 1 Flow diagram of the step by step proposed protocol

2.1 First step: Mix age assessment

In the test method proposed, the times required for the grout to reach some specified values of slump loss are used to define times of ageing and as a consequence the mix limit of use. This test method can be used to determine the effects of variables, such as yield stress that it is considered one of the indicators of workability. The determination of the slump flow on the time by means of using the Abrams cone [5] is the base of the method proposed for the determination of mix ageing. Regarding limit values they will depend on the work site conditions. On the designing stage the curve slump vs. time has been determined in order to check if the associated workability time is reached and also to known the curve evolution for latter on site QC just in case the mix fit owner demands.

2.2 Second stage: Flowability determination

Flow-ability or fluidity is a measure of how well a mixture will flow without segregate or bleed. When it is being placed, the term as defined encloses also fill-ability. ACI [6] also refers as ***flowable fill*** to a self-compacting cementitious material that is in a flowable state at placement. It is important to remark that flowability assessment means something more than consistency assessment (the usual measured parameter) as it is the concurrently determination of at least three parameters **(i)** fluidity, **ii)** segregation resistance and **iii)** relative viscosity while consistency assessment only gives information related fluidity.

For backfill flow-ability assessment as it has been defined that the determination of the slump flow as well as the flow time by means of using the Abrams cone (in an inverted instead of upright position) is the base of the method proposed for the determination of the main properties ((**i)** fluidity, **ii)** segregation resistance and **iii)** relative viscosity) to quantify the approach to the segregation threshold. To measure all these properties efficiently, and without the need for cumbersome specialized equipment, the slump flow method [7][8] may be combined with the T50 [7] and Visual Stability and may be conducted concurrently. Regarding the limits proposed it is noteworthy to say that similar ones than for SCC lead to obtain a backfilling capable to flow properly into the void.

2.3 Pumpability assesment

Considering that Pumpability is the ability of a given mix to be pumped with the available pumping equipment in actual conditions (length, height, pipe diameter, etc.) and the lack of appropriate equipment to measured it properly a new dedicated device (pumping rheometer [9]) has been developed by the authors in order to assess pumpability properly.

The pumping rheometer allows the determination of flow F and pressure P under lab conditions (see fig. 2). Although the mathematical model is still under development it is possible at the moment to discriminate between pumpable and not pumpable mixes by examining P/F curves. It is possible to check the increase in the pressure needed for a given flow on the mix M2 compare with the one of M1. This high pressure gauge is a good indicator of a possible malfunctioning that can lead to incorrect backfill injection.

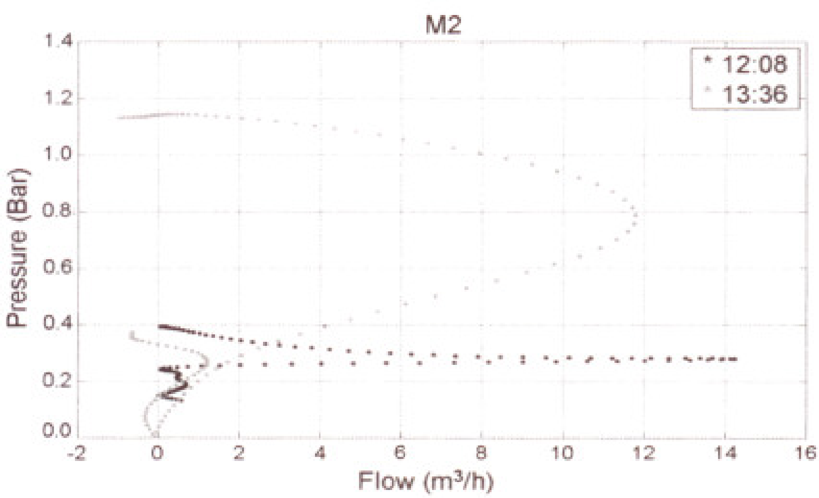

Fig. 2 Plot of Pressure vs. Flow values of mix M1 (blue) and mix M2 (green)

2.4 Setting time and strength evolution assesment

For determining setting time and strength evolution a NDT method is also proposed [10][11]. This method based on the electrical resistivity determination by using the Wenner array probe allows the determination of the resistivity curve along time for both the initial period and latter on (if concrete humidity conditions are the properly ones) see Fig 3 and 4. As it is possible to see on Fig. 3 a maximum conductivity point (P_m) appears. This can be identified by a decrease of resistivity due to the increase of ions in the liquid phase which favours the conductivity. The time to reach the saturation point for each mix is therefore affected by the w/c, the type and dosage of the admixture and the cement type. Then it is possible to identify the period where the electrical resistivity gradually increases with time, indicating a decrease in porosity and increase in tortuosity (hydrate nuclei consumes the ions in the solution while a reduction in porosity occurs). Afterwards, the rapid hydration leads to significant increase in the resistivity. This change on the slope determines P_f. On this way both initial and final setting time can be determined.

Last but not least (see Fig. 4) is possible also to determine the strength evolution by means of the electrical resistivity as a correlation between both exist [10].

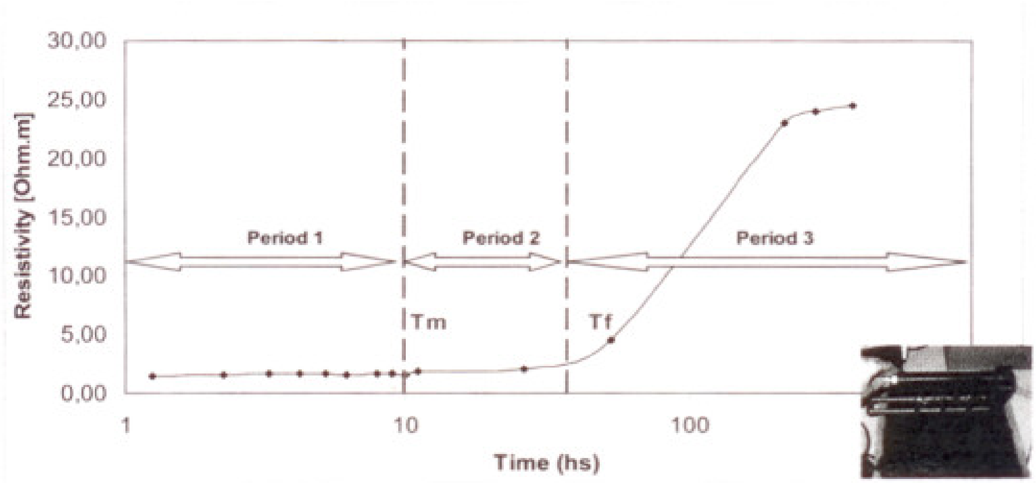

Fig. 3 Electrical resistivity vs. elapsed time of a grout (log scale)

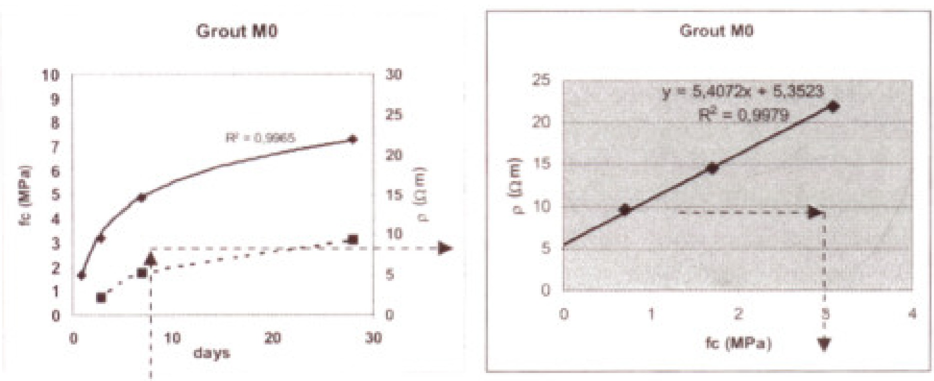

Fig. 4 Plot of resistivity (ρ) and mechanical strength (f_c) versus elapsed time (left) and of resistivity vs. mechanical strength at different ages (right)

3 Conclusions

Although these conclusions should be taken as preliminary as real scale tests must be done, the results obtained up-to-date allow the following remarks to be made:

- The definition of a PBG is possible if the above protocol is used.
- The protocol it is also useful to be applied on site for QC issues; and the preliminary experimental results show the feasibility of its use.

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