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[Christodoulou* 9(4): April, 2022] ISSN 2349-4506
Impact Factor: 3.799

Global Journal of Engineering Science and Research Management

PARAMETERS SIGNIFICANTLY AFFECT THE SETTING TIMES OF CEMENT SUSPENSIONS FOR SOIL GROUTING – A MINI REVIEW

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KEYWORDS: Soil Improvement; Permeation Grouting; Cement Suspensions; Setting Times.

ABSTRACT
Improvement of the mechanical properties and behavior of soils by permeation grouting, using either suspensions or chemical solutions, is frequently required in order to assure the safe construction and operation of many structures. Suspensions have lower cost and are harmless to the environment but cannot be injected into soils with gradations finer than coarse sands. Chemical solutions can be injected in fine sands or coarse silts but are more expensive and, some of them pose a health and environmental hazard. Efforts have been made to extend the injectability range of suspension grouts by developing environmentally friendly materials with very fine gradations. Setting times and early strength development of cement grouts are measured on the sediments produced after completion of bleeding. When the bleed capacity is small or negligible, the water-to-cement (W/C) ratio of the sediments is, practically, equal to the W/C ratio of the grout.

INTRODUCTION
The initial stage of a comprehensive investigation of soil improvement with suspension injections consists of a series of tests to determine suspension properties. Suspension grouts are the most economical solution, but at the same time they show many important disadvantages such as the inability to develop endurance and the difficulty of penetration. The most popular suspension type grouts are those based on cement, which have Portland cement and water as their main components. Depending on the needs of each application (high initial strength, resistance to chemical environment) it is possible to use different types of cement (aluminum, slag, etc.) instead of common cement. In addition, it is possible to add to the grouts some solids (sand, clay) with the main purpose of reducing the cost of injections, while the use of admixtures such as fly ash, slag and silica fume and the addition of chemical improvers (superplasticizers, water reducers, coagulation accelerators etc.) aims to improve some properties. Since then, several research efforts have been made towards documenting environmentally friendly materials with an emphasis on improving the properties of cement suspensions such as initial and final setting times [1-8].

DEFINITIONS
In cement suspensions, the setting process is divided into two stages: in the initial stage in which the fluidity of the suspension decreases to a level after which it is no longer pumpable (coagulation stage) and in a second stage in which the suspension hardens and increases its endurance (hardening stage). In the coagulation stage there are two sub-periods known as “initial” and “final” setting times. The initial setting time is defined as the time between manufacture and partial loss of workability of the suspension, while the final setting time is defined as the time required for the suspension to have sufficient strength [9, 10]. Many researchers also distinguish a third period (dormant period), which is equivalent to the time from mixing the components of the suspension required to begin the chemical processes that lead to coagulation [11, 12], but it is usually incorporated in the initial coagulation stage. Usually, the stage of coagulation and that of hardening do not overlap, while it has been found that the rates of coagulation and hardening are not related. The hardening stage of the suspension begins at the end of the final coagulation, continues for a long time (a few months or years) and is accompanied by an increase in its strength [9, 10].

DETERMINATION OF SETTING TIMES
The determination of the initial and final setting time is based on both European (EN 196.03: 2005) and American Standards (ASTM C191-04a) in the experimental Vicat needle penetration procedure. Attempts have been made to correlate clotting times with other properties and especially with durability. More specifically, according to Littlejohn [9], the initial setting time according to Vicat corresponds to a shear strength value equal to 17.25 kPa, while by De Paoli et al. [13] state that the initial setting time corresponds to the time required for the suspension

to have a shear strength of 18 kPa. Finally, it has been observed that Vicat needle penetration test results are in good agreement with strength measurements using a pocket penetrometer [10]. In particular, it appears that the initial setting time is equivalent to that for a strength value of 50 kPa and the final setting time is equivalent to that for a strength value of 450 kPa.

EFFECT OF CHEMICAL ENHANCERS ON SETTING TIMES

Knowledge of setting times, especially the initial setting time, is considered extremely important when designing suspensions, as such a short time (<4 hours) can damage the injection equipment, while a long time (> 24 hours) can cause significant delays in the process and significantly reduce the effectiveness of injections [14]. Also, it is often considered necessary for these times to be regulated according to the requirements of each project. For example, in cases where injections are made below the aquifer then it is desirable to accelerate the coagulation of the suspension [14]. In contrast, in cases where multiple-stage injections are provided, the initial setting time should be slowed down to allow homogenization between new and already compressed suspension volumes and to avoid inhomogeneities and difficulties in further injection stages [15, 16]. Setting times can be adjusted according to the needs of the project, without changing the final properties of the suspension [17]. Various chemical enhancers such as retarders, accelerators and inhibitors are used to regulate the final clotting times [9, 16]. With retarders, the rate of hydration is reduced and thus the clotting times are prolonged [16, 18], while the use of accelerators has the opposite effect [19, 20, 21, 22, 23]. With inhibitors, the progress of the hydration process is stopped (and not slowed down as is the case with retarders) without any detrimental effect on the coagulation properties of the suspensions in the long run. In contrast, it has been found that with the use of inhibitors the coagulation properties of suspensions are better compared to pure suspensions [22]. The addition of superplasticizers and/or flow regulators has an indirect effect on the setting times of cement suspensions, as their use seems to lead to an increase in both the initial [14, 16, 18, 20, 24, 25] and final setting time [20, 25]. It also seems that in this direction the effect of melamine-based superplasticizers is greater than those with naphthalene-based ones [14, 24]. It has been observed that large variations in coagulation times occur between suspensions containing the same ingredients in the same contents but different types of superplasticizers. This is mainly due to possible incompatibilities between the materials and therefore, it is considered that preliminary tests should be performed in the laboratory before any application in the field [14].

EFFECT OF CEMENT TYPE AND FINENESS ON SETTING TIMES

The type and fineness of the cement used as a base for preparation of the suspensions have a significant effect on the setting times. It has been observed that increasing the fineness of cement grains leads to a reduction in the initial setting time [9, 14, 18, 25, 26, 27], which takes on larger dimensions especially at low W/C ratios. This effect seems to be reversed when the fine-grained cements contain a significant slag content. For example, initial coagulation times of 1 hour and 20 hours have been reported for Portland pure cement and slag cement suspensions, respectively [28], with similar findings by Henn et al. [29, 30]. Also, results from measurements of final setting times showed that fine-grained pure Portland cements, regardless of W/C ratio and superplasticizer content, show dramatically shorter setting time (1-15 hours) than slag (15-45 hours) [14]. This phenomenon is attributed to the low activity of slag granules which significantly delays the progress of the hydration process [14, 28, 29, 30]. For the same reason, the addition of materials such as bentonite [10, 31], fly ash [18] and silica fume [20] causes an increase at the setting times of cement suspensions. In these cases, however, in order to understand the effects of the admixtures, their content must be at relatively high levels (10% for bentonite and 15% for silica fume).

EFFECT OF WATER-TO-CEMENT RATIO ON SETTING TIMES

The extent of setting times depends significantly on the rate of hydration process that takes place in the cement suspensions. Since the W/C ratio plays a dominant role in the progress of hydration, it is understood that it also has a significant effect on clotting times. It is considered acceptable that the reduction of W/C ratio is one of the basic measures to reduce both the initial (14, 20, 27, 32, 33] and the final setting time (14, 20, 32]. It is typically reported that suspensions with W/C ratio equal to 1:1 and a superplasticizer dose of 1.5% by weight will have initial and final setting times ranging from 1 to 2 hours and from 2 to 2.5 hours, respectively [22], on the contrary, suspensions with high W/C ratios (≥ 4:1) will show an initial setting time of more than 20 hours [34].

DISCUSSION

Based on the available literature, the following conclusions can be advanced:

1) Setting times and early strength development of cement grouts are measured on the sediments produced after completion of bleeding. When the bleed capacity is small or negligible, the water-to-cement ratio of the sediments is, practically, equal to the water-to-cement ratio of the grout.
2) The addition of superplasticizers and/or flow regulators has an indirect effect on the setting times of cement suspensions, as their use seems to lead to an increase in both the initial and final setting time.
3) It has been observed that increasing the fineness of cement grains leads to a reduction in the initial setting time, which takes on larger dimensions especially at low water-to-cement ratios. This effect seems to be reversed when the fine-grained cements contain a significant slag content.
4) The addition of materials such as bentonite, fly ash and silica fume leads to an increase of cement suspensions setting times.
5) It is considered acceptable that the reduction of the water-to-cement ratio is one of the basic measures to reduce both the initial and the final setting time.

ACKNOWLEDGEMENTS

Grateful appreciation is extended to Ioannis N. Markou, Associate Professor of Civil Engineering Department of Democritus University of Thrace (D.U.TH.) for his insightful critique of this research effort and its successful funding. The research effort reported herein is part of the research project PENED-03ED527, which was co-financed by the European Union - European Social Fund (75%) and the Greek Ministry of Development—General Secretariat for Research and Technology (25%). The contribution of TITAN Cement Company S.A. was substantial for the selection, chemical analysis, pulverization, and grain-size analysis of the cements.

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