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The plate test carried out on fresh cement-based materials: How and why?

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ABSTRACT

The plate test consists in measuring the mass variation of a rough tool (plate or cylinder) immersed in a fresh cement-based material with time. It has been used to study the evolution of the rheological behavior of cement-based materials with time. This device was initially developed to enable a simple measurement of the increase of the yield stress. Therefore, it can provide an accurate value of the structuration rate during the so-called dormant period and also provide an evaluation of the initial setting time.
However, as the immersed tool remains static, the success of the test depends on the movement of the cement-based material at the interface. The relative translation between the freshly made cement-based material and the tool must be sufficient to overcome the critical shear strain of the sample. During the very early age of the cement-based material many phenomena occur (consolidation, shrinkage, thermal expansion, bleeding…) and lead to volume variation of the material. Those volume variations need to be controlled in order to ensure a correct measurement of the yield stress. After providing and explaining the test physical background and procedure, we first aim to warn researchers about possible measuring artefacts that lead to a too low strain at the tool interface.
Then, this paper shows all the possibilities and information provided by during the dormant period and setting. In this paper, an attempt to extend the test duration and to get also information on the thermal expansion is presented. This paper shows how to perform a successful and highlights the versatility of the plate tests that is able to provide interesting information about structural build-up, setting and thermal expansion.

1. Introduction

Despite the long tradition of characterizing cement paste time evolution by the initial and final setting time, these values are not sufficient to answer some of the more practical questions related with constructability. The answer to these questions is of paramount importance for the civil engineer to plan a concrete delivery for a given construction site. However, to answer the above questions, the flow properties of the material and their evolution need to be known. In contrast with a mechanical method that will be always dependent on the geometry and the applied forces, the proposed investigation was carried out on the idea that it was possible to monitor the setting through the variation of yield stress. Roussel and other authors have shown that during the dormant period and at rest, self-compacting concrete (SCC) structure build-up and its yield stress increases [21,22,24,27]. This increase is responsible for lot of practical application such as multilayer casting, 3D printing, formwork pressure decay… [3,4,14,18,19,21,23,26]. The increase rate of yield stress is commonly determined using rheological measurements carried out after different resting time. Portable system has been developed to monitor the yield stress increase on site [3,4,8]. Another strategy is to use the plate test measurement [1,3,4,6,25,26]. The plate test device, consisting of a rough plate (or needle) immersed in the fluid sample, was developed to enable a simpler measurement of the increase of the yield stress of non-Newtonian suspensions such as self-compacting concrete. Due to the deformation of the material at rest along the vertical axis, shearing appears at the plate surface inducing the plate apparent mass to vary with time.

The plate test device has been first used for concrete in 2008 [1,26]. The problem is the same as the steel rebar immersion in concrete formwork [15]. The elastoplastic properties and deformation of the fresh cement paste are used. Due to local vertical deformation of the cement paste at very early age (shrinkage, dilatation, settlement), stresses are mobilized at the interface between the paste and the rough plate. This induces variation of the apparent mass of the plate or needle, as proposed by Sleiman et al. [25]. Moreover, since the plate or needle is static and the material shrinkage is slow, the dynamic effects are, therefore, negligible. The plate tests measurements have also been shown to be able to give accurate values of the setting times [25]. However, as the

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immersed tool remains static, the success of the test depends on the movement of the cement-based material at the interface. The relative translation between the freshly made cement-based material and the tool must be sufficient to overcome the critical shear strain of the sample. During the very early age of the cement-based material many phenomena occur (consolidation, shrinkage, thermal expansion, bleeding…) and lead to volume variation of the material. Those volume variations need to be controlled in order to ensure a correct measurement of the yield stress. Therefore, to obtain an accurate measurement and to adequately analyse the data, it is required to perform an accurate protocol of the test. Many measuring artefacts can lead to a wrong description of the material evolution.

The paper aims to provide a correct protocol for performing a plate test measurement carried out on SCC that is able to provide the rate of increase of yield stress during the dormant period and the setting times. We try to extend the test duration from the final setting time to 24 h in order to see what other information can be provide by the plate tests. The plate test was able to detect the thermal expansion due to exothermic hydration of the cement particles. We also try to give some limitations of this test that is able to provide important data when properly carried out.

2. Methods and physical background

2.1. The plate test: a multiform apparatus

The plate test device can take several forms. It is composed of a tool immersed in a freshly made material (needle or a plate) rigidly attached below a fixed support. The mass variation of the sample or of the tool is recorded i.e. the apparent mass of the immersed tool or the apparent mass of the sample is continuously recorded with a balance linked to a computer. It is important to note that the balance can be used to measure the immersed tool apparent mass and the sample apparent mass for two possible test configurations because both mass variations remain equal. Measuring the mass of the sample remains easy when a limited volume of material is tested. However when tenths of liters of SCC are tested, it becomes more convenient to measure the apparent mass of the immersed tool.

The immersed tool used can be a needle with a diameter of 1.13 mm ± 0.05 mm and 40 mm long (i.e. a roughened Vicat needle) [25], can be a plate covered by sandpaper [1,6,26] or also a 10 mm or more diameter rebar [3,4,15]. The distance between the needle/plate and the container walls is large enough that there is no influence on the stress measured due to the size of the frustum as shown by [28] and Tchamba et al. [26]. Moreover, in order to ensure that the yield stress is fully mobilized at the interface with the immersed tool, it is critical to ensure that the critical strain is overcome at the interface. Therefore, as the plate remains static, the vertical settlement of the tested cement-based materials must be sufficient.

It can be noted that all types of cement-based materials can be tested from cement paste to concrete (Fig. 1).

Measurement precision and reproducibility depend on the precision of the recorded following parameters: a) immersion depth, b) measured mass and c) experimental conditions such as temperature and relative humidity (avoid drying effects). In the previous studies using plate tests variations between tests performed on the same material in the same experimental conditions are less than 5% [1,3,4,25].

Additional measurements can be performed during the tests in order to obtain complementary data such as surface settlement or temperature variations. As example, In addition to the Vicat static test performed in a previous study of Sleiman et al. [25], the surface settlement (i.e. the material vertical deformation) is measured with a comparator (LVDT) placed on the material surface. A small steel grill is placed between the comparator and the cement paste to reduce the error due to comparator weight. This measurement is used to check if the settlement is sufficient to reach the critical strain at the interface. The simultaneous measurement of the temperature is also interesting because it is a way to follow the chemical activity and to check thermal expansion. All tested materials are summarized in Table 1.

2.2. Physical background and equations

During very early age (the first 24 h), the cement-based material undergoes several physical and chemical evolution that lead to dimensional variations. Those dimensional variations are responsible for the shearing of the tested material at the interface of the immersed tool. Therefore, it is important to understand what is occurring within the material in order to explain the recorded mass variation.

The first phenomenon occurring is consolidation that is responsible for the bleeding [7,12,20]. When the colloidal network of cement grains

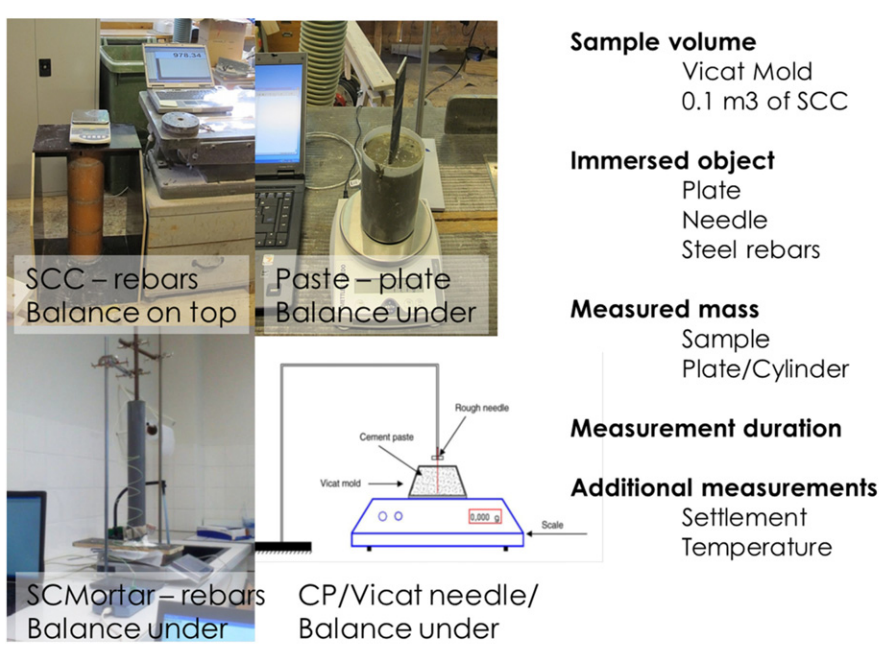

Fig. 1. Different configurations of plate tests from a cement paste tested in a Vicat mould to a SCC tested in a column of 100 l.